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THE

# AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

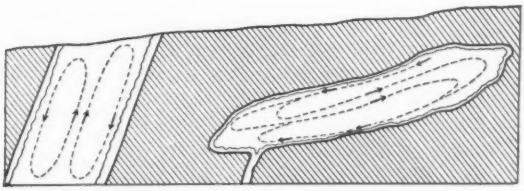
## ART. XXVIII.—*Fractional Crystallization of Rocks;* by GEORGE F. BECKER.

AMONG the phenomena most often appealed to in support of the theory of magmatic segregation or differentiation is the symmetrical arrangement of material in certain dikes and laccolites. This separation seems to me readily explicable in certain cases without resort to the hypothesis of the division of a homogeneous fluid into two or more distinct fluids. I have already called attention to the process in brief terms;* though very well known it has not otherwise been invoked, so far as I am aware, to explain rock differences. If the suggestion has previously been made, it seems time that it should be repeated. If we suppose a dike in cold rock filled with mobile lava which does not overflow, or has ceased to overflow, the mass will be subjected to convection currents, because the liquid near the walls will be cooler than that near the median plane of the dike. A circulation of lava will then take place, the descending flow at the sides being compensated by ascending flow near the central surface. The conditions are roughly represented in the diagram below. If the lava is a homogeneous mixture of two liquids of different fusibility, then the crusts which first form upon the walls will have nearly the same composition as the less fusible partial magma. If one follows mentally a small portion of the liquid in its circulation, it will clearly deposit at each of its early contacts with the growing

* This Journal, vol. iii, 1897, p. 39.

walls a part of its less fusible component, and at each completed revolution it will have a different composition. This composition will always tend towards that which represents the most fusible mixture of the component compounds. When this composition is attained, the magma will no longer undergo change by circulation and partial solidification; and the residual mass will gradually solidify as a uniform material. Unless then the injected magma happened to be a mixture of maximum fusibility, the dike would exhibit a gradation in composition from the sides towards the center. In a very narrow dike solidification might take place before an opportunity was afforded for the complete elimination of the less fusible material; while in wide dikes solidified from mobile magmas one might expect the central sheet to approximate to maximum fusibility.

It is evident that the process of solidification in a laccolite closely resembles that in a dike, particularly if the section of greatest area is not absolutely horizontal. Convection will then be set up and solidification from the walls must tend to the evolution of a residuum of extreme fusibility.



Convection in dikes and laccolites.

The process sketched is one of the most familiar in chemistry and is usually known as fractional crystallization. It has been employed in the purification of compounds ever since chemistry was pursued, and indeed before; for the preparation of salt from sea water or brine depends upon it. It can be and has been employed also to strengthen solutions. A familiar instance is the freezing of weak alcoholic liquids. A bottle of wine or a barrel of cider exposed to a low temperature deposits nearly pure ice on the walls, while a stronger liquor may be tapped from the center. If a still lower temperature were applied the central and more fusible portion would also solidify. Such a mass would be, so far as I can see, a very perfect analogue to a laccolite. A similar concentration is effected in the Pattinson desilverization process.

Though fractional crystallization is said to have been familiar to Parcelsus and even to Aristotle, the process has been studied most thoroughly by Mr. F. Guthrie.* As is well known, he

* Phil. Mag. (5), vol. xvii, 1884, p. 462.

names the property of maximum fusibility in mixtures eutexia and the bodies which exhibit this property he calls eutectic. The phenomena are not always so simple as is supposed in the illustration given above, especially when masses, as they approach the temperature of solidification, divide into immiscible fractions. In such cases one has to do with two or more eutectic mixtures. Supersaturation may also intervene to complicate matters and change of pressure probably influences the composition of the eutectics.* Thus it is at least conceivable that very complicated cases should arise, while if the process plays a part in lithogenesis the simplest case is probably the most frequent.

The fractional crystallization process depends essentially upon convection currents. That it is not incompatible with convection is clear, while convection is the mortal enemy of any process of separation involving molecular flow. The only function of diffusion in this case would be to preserve the homogeneity of the residual fluid or mother liquor, so that the eutectic state could not be attained by any sensible part of the fluid until the whole mother liquor was reduced to this condition.

The effect of the solidification of crusts on the walls of a dike or laccolite is to liberate heat. This liberation does not raise the temperature, for otherwise the crusts would remelt; but the liberated heat must be conducted through the walls before the dike as a whole can congeal, and it therefore delays the process of solidification, giving additional time for the evolution of an eutectic magma.

There appear to be some conditions under which eutectic action could not be expected. Unless an intrusive rock possesses considerable mobility, chilling would proceed more rapidly than convection, and eutectic separation would be very imperfect if not completely obscured. Viscosity of the mass would also interfere seriously with the uniformity of composition of the mother liquor. If the mass cooled very slowly indeed, this uniformity might be established even in a very viscous mass; but very slow cooling would also mean very slight convection. In viscous lavas, therefore, fractional crystallization is not very probable. There is seemingly no exact way of defining the degree of viscosity compatible with fractional crystallization, but enough mobility must certainly be present to maintain uniformity in the melted mass when diffusion and convection coöperate. I have shown that, in some solutions at any rate (all for which I could find appropriate experimental data) diffusivity is inversely as the square of viscosity.† If any such law holds for magmas, a moderate amount

* Ostwald, Allgem. Chemie, vol. i, 1891, p. 1027.
† This Journal, vol. iii, 1897, p. 284.

of viscosity would preclude the formation of eutectic mother liquors.

Eutectic mixtures by definition would have no tendency to fractional crystallization however fluid they might be and however strong the convection currents. Where dikes represent the last remnant of magma in a solidifying mass, one would expect to find them of eutectic composition, as has been pointed out by Mr. J. J. H. Teall.* Convection being needful to fractional crystallization, it would seem essential that the cooling magma should be surrounded by masses of a lower temperature.† In the case of dikes this condition is ordinarily fulfilled. On the other hand, if laccolites ever form and solidify without ejection at great depths and in contact with rocks of high temperature, it seems improbable that convection and partial crystallization would come in play to a sensible extent.

It is difficult to see how so simple and natural a process of solidification as fractional crystallization can fail to be carried out in at least some rocks. Dikes and laccolites assuredly chill from their external surfaces and (barring either an original eutectic composition or insuperable viscosity) there seems no way of avoiding fractional crystallization. It has often been noticed that there is an accord between the order of consolidation of minerals as observed under the microscope and the arrangement of minerals in dikes, the compounds of early secondary crystallization being most abundant near the walls. This is of course what would be expected from a process of fractional crystallization. Observation would no doubt throw further light on the composition of eutectic rock mixtures. Narrow stringers from a so-called "basic" dike would represent the mean composition at the time they were filled; and unless the composition of the magma changed during flow, the stringers should represent the average dike rock. The middle portion of the dike, on the other hand, should tend to display eutexia. Dikes which are homogeneous ought to be eutectic. Many experiments have already been made on eutectic mixtures of salt both in the dry and the wet way. It does not seem impossible that experiments on eutectic mixtures of rock components should give results of an approximation sufficient for the purposes of lithology.

Few, I believe, will maintain that any great progress has been made in explaining the theory of the segregation of magmas into partial magmas. Mr. H. Bäckström,‡ for example,

* British Petrography, 1888, p. 401.

† Dr. W. F. Hillebrand reminds me that the changes in density of the mother liquor during crystallization will of themselves induce convection, though perhaps not powerful currents.

‡ Jour. of Geol., vol. i, 1893, p. 773.

denies the applicability of the Ludwig-Soret law. In this he seems to me correct, but I fail to see that he gives adequate reasons for the rejection. He resorts to the separation of magmas into immiscible fractions for a working hypothesis, but without showing how the necessary variations of temperature are to be accounted for. Mr. Alfred Harker* also regards the Ludwig Soret law as inapplicable to magmatic segregation, which he seeks to explain by the molecular flow attendant upon crystallization. The maximum rate of molecular flow is thus provided for, but I have shown that even under these most favorable circumstances the time required for the separation of considerable masses of material from one another would be practically infinite in any solutions of known properties. Mr. Michel-Lévy again, whose researches in physics give his opinions on the segregation of magmas the greatest weight, has reviewed the hypotheses of Messrs. Brögger and Iddings. He points out the enormous time required for the process and, as others have done, the impeding influence of viscosity. The results of experiment, he thinks, are more favorable to the old theory of superposition of magmas in the order of decreasing density. He finds many objections both to the hypotheses and to the evidence in their favor, and the only point which he regards as certain is that there are some consanguineous rocks. These, he thinks, probably came from a reservoir in which the initial magma has undergone only such modifications as were consistent with the preservation of its distinct individuality.† It seems needless to enlarge further on the unsatisfactory condition of the theory of differentiation.

On the other hand, the simple principle of fractional crystallization, which is the very opposite of magmatic differentiation, is in most respects thoroughly well understood, it is known to be practicable by hundreds of thousands of experiments, many of them on a fairly large scale, and its action is so rapid as to bring about in days diversities of composition which it would take centuries to bring about by processes depending on molecular flow. In dikes and laccolites of mobile lavas fractional crystallization seems inevitable, while the convection attending it is inconsistent with segregation by molecular flow. Surely it is worth the while of lithologists to consider in how far differences in such rocks as are beyond a doubt genetically connected can be accounted for by a process which is almost inseparable from consolidation.

Washington, D. C., June, 1897.

* Quart. Jour. Geol. Soc. London, vol. l, 1894, p. 311.

† Bull. Soc. Geol. de France (3), vol. xxiv, 1896. p. 123. I should have been glad to reinforce some of the reasoning in a paper printed in this Journal, vol. iii, p. 21, by reference to Mr. Michel-Levy's paper cited above; but it did not come under my eyes in time.

ART. XXIX.—*Eopaleozoic Hot Springs and the Origin of the Pennsylvania Siliceous Oölite;* by GEO. R. WIELAND.

IN seeking for more direct evidence as to the origin of the *siliceous oölites* occurring near the Pennsylvania State College in Center County, Pennsylvania, I have been led to the consideration of certain associated flint bowlders of unusual regularity of structure.

Before describing these, however, it may be well to mention that this siliceous oölite is the most perfect and beautiful of all the oölites, and that its description* was the first given of a characteristic siliceous oölite. Previously several occurrences of cherts merging into oölite had been mentioned. Since then, siliceous oölites of more or less distinct structure, and undoubtedly of various origin, have been reported from widely separated localities, and geological horizons, though none are known to be more recent than the Paleozoic. The cherts of Missouri which often merge into a semi-oölitic structure have been studied by Hovey.*

But the oölites containing a large percentage of silica not only vary much in structure, but much too greatly in composition to prevent any general statement as to their origin. This is shown by the following analyses, made by the writer while a student in the laboratory of the Pennsylvania State College:

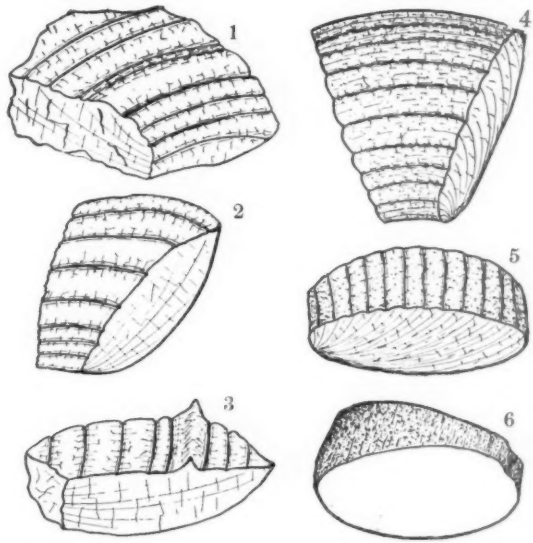
| | I. | II. | III. |
|---|---|---|---|
| $SiO_2$ | 65·34 | 96·13 | 99·10 |
| $Fe_2O_3$ | ---- | 1·13 | ·11 |
| $Al_2O_3$ | ---- | ---- | ·17 |
| CaO | 10·35 | .... | ·39 |
| MgO | 7·91 | ·97 | -- |
| $K_2O$ | ---- | ·58 | -- |
| $CO_2$ | 15·24 | -- | -- |
| $H_2O$ | 1·85 | ·93 | ·25 |
| | 100·69 | 99·74 | 100·02 |

No. I is an oölite of granular texture, and in fact consists of spherules of silica with a gangue of dolomite. This rock was observed by the writer in a stratum of some twenty feet in thickness near Rockwood, Tennessee. It was only casually examined. A mile away on a lower horizon the iron oölite of the Clinton was being mined. II is from the same locality. III is the remarkably regular spheruled variety from

* Barbour and Torrey: Notes on the Microscopic Structure of Oölites with Analyses, this Journal, September, 1890.

the Pennsylvania State College locality. A smaller spheruled rock occurring in greater quantity contains about a half per cent less of $SiO_2$ with more iron, alumina and magnesia.

Without attempting to take up the origin of oölites in general, however, I merely mention that two writers working independently of each other have from the microscopic study alone assigned the Pennsylvania oölite as due to direct deposition from the silica-laden waters of hot springs.* This con-




Built-up chalcedony bowlders of the Pennsylvania siliceous oölite locality.—$\frac{1}{2\frac{1}{3}}$ actual size. Figs. 1, 2, 3, 4, 5, supposed actual rim bowlders. Fig. 6, supposed core bowlder.

clusion is no doubt correct. A hand specimen found recently consisting of spherules of small size up to pisolitic intermingled with chalcedony-coated pebbles points to its truth.

But probably the most convincing testimony to the existence in the Calciferous of a limited area of hot springs from whose silica-laden waters these siliceous oölites were deposited, lies in the fact that in the limited oölite area and nowhere else in the entire region are found in considerable number bowlders of a built-up structure which may have formed the rims of hot springs or geysers. Types are shown in figures 1–6

* E. O. Hovey, Geol. Soc. of Am., vol. v, 1893. Dr. W. Bergt, Ges. Isis in Dresden, 1892.

above. The most distinct of these bowlders are found within an area of less than one square mile, and this is exactly the area of the best marked oölite. It should be stated that neither oölite nor bowlders have ever been observed except as surface debris. This may be due to the fact that the oölite probably never formed a very continuous stratum, as well as to the fact that there is neither rock exposure nor excavation within the oölite area. Both bowlders and oölite no doubt belong to the underlying rock, which I suppose from its position and the character of exposures of the same horizon at another point to be Calciferous. There occur associated with the oölite at one or two points, certain bowlders showing only traces of oölite which contain nearly obliterated traces of numerous fossils. I would say that brachiopods, cyathophylloid corals, a gasteropod, and numerous orthoceratites are represented.

The cuts of the bowlders illustrate their form and cleavage fairly, but do not show the pitting of the surface due to weathering. The bowlders are much iron-stained and somewhat granular in texture, though breaking most readily along the cleavage planes which radiate from the inner edge of the circular rims of which they may be regarded as segments. The direction and position of these planes are best shown in figs. 2, 4, and 5. What was probably the upper surface is roughly but regularly grooved, as best shown in fig. 1. These groovings mark more or less nearly the emergence of the cleavage planes just mentioned. The bowlder shown in fig. 6 lacks the built-up structure, and may have formed within an already formed rim. There are occasional small rhombohedral cavities as in the oölite itself,—a pseudomorphism after calcite.

Under the microscope the material is found to be chalcedony, with small crystal inclusions which were too minute to determine. I suspect these crystals to be biaxial, and they may be from their shape hornblende.

The rims which these bowlders formed had an inside diameter of from two to six feet. The inner edge is always preserved, while the outer is often irregular or broken away. We may readily conceive the bowlders as having formed the rims of a number of hot springs or geysers near a low-lying shore of the Calciferous. The dissolved silica first deposited would have formed rings, that deposited while in more rapid motion the small spheruled oölite, which is most plentiful near the best marked of the rim bowlders. Lastly would be formed large grained oölite, the compact and pure quartzite, which is the handsomest oölite known. That in accounting for the origin of this oölite hot springs or geysers of the Calciferous may actually be located is an interesting consideration. While the writer has not had an opportunity to examine a geyser region, he believes that further investigation will sustain his view.

Chester, Pa.

ART. XXX.—*On the Conditions required for attaining Maximum Accuracy in the Determination of Specific Heat by the Method of Mixtures;* by F. L. O. WADSWORTH.

*Introductory Note.*—In the last volume of the Proceedings of the American Academy, which has just been received at the Observatory, I find a paper by Professor Holman* discussing methods of making the "cooling corrections" in determining specific heat by the method of mixtures. In this paper the author has suggested that this correction may be simplified by a modification of the usual method which "is supposed to be new." This suggestion is of the same nature as one which I made some years ago and embodied in a paper which formed part of my report in laboratory work at the Ohio State University for 1888–89, but which was never published. The investigation was undertaken as preliminary to an accurate determination of the specific heat of the metal of one of Professor Rogers' standard bars, a sample of which had been sent to Professor Thomas for that purpose. No opportunity was given at that time to put the suggested method to actual test, as it was subsequently decided to use the ice calorimeter instead.

The method differs from that suggested by Professor Holman in that it goes further and eliminates the necessity for the cooling correction entirely. Except for that part of the paper (pp. 274–277) which deals with the conditions for securing this result, there is nothing novel or particularly original in the treatment. But as the whole discussion is more or less linked together and as it will serve to supplement to some extent Professor Holman's paper, which deals only with the cooling correction (the most important but not the only source of error in calorimetric determinations), it has been decided to let the paper stand as it was first written (except for a slight rearrangement of the order of the paragraphs), supplementing the original text with footnotes where it seemed necessary. At the end will be found a few general notes relative to the arrangement and use of apparatus in the determination of specific heat by both the method of mixtures and the method of the ice calorimeter. These notes did not form part of the original paper, but have been added from time to time as suggested in my laboratory experience. The method of discharging the hot body from the heating vessel and receiving it in the calorimeter, and of maintaining the jacket of the latter at a con-

* "Calorimetry: Methods of Cooling Correction," Proc. Amer. Acad., vol. xxiii, p. 245, 1896.

stant temperature will, I think, be found especially reliable and convenient.

. . . . . .

In the method of mixtures the body whose specific heat is to be determined is first raised to a known temperature, then immersed in a known quantity of water and the rise of temperature of the water noted. In the operation it is of course necessary that the water be held in some form of vessel which will be heated in common with the water, and which in turn will heat the surrounding air by radiation. However, taking first the theoretical case and supposing no heat lost by radiation, but all used in raising the temperature of the water, the containing vessel and the thermometer used to indicate the rise in temperature, we have the well-known equation

$$s\times(\mathrm{T}-\theta)\times w=\mathrm{M}c(\theta-t)+\mathrm{M}'c'(\theta-t)+\mathrm{M}''c''(\theta-t) \qquad (1)$$

where $s$ .. is the specific heat of the body under experiment;
$w$ .. " weight " " "
T .. " temperature " " before immersion;
M .. " weight of water in the calorimeter;
$c$ .. " mean specific heat of the water for the interval $\theta-t$;
$t$ .. " temperature of the water before the body $w$ is added;
$\theta$ .. " temperature of water, vessel and body after equalization has taken place;
M′, $c'$ .. are the weight and specific heat of the vessel containing the water, i. e., the calorimeter;
M″, $c''$ .. " weight and specific heat of the thermometer.

This formula is generally simplified by putting $m'c'+\mathrm{M}''c''=\mathrm{W}c$, where W is the water equivalent of the calorimeter, viz: the amount of water which for a given rise in temperature, $\theta-t$, will absorb the same amount of heat as the calorimeter and the thermometer will absorb.

Making this substitution and solving for $s$ we get

$$s=\frac{(\mathrm{M}+\mathrm{W})\,c\,(\theta-t)}{w(\mathrm{T}-\theta)}. \qquad (2)$$

Now in practice the quantities M, W, $w$, $\theta$, $t$ and T, must all be observed ($c$, we have determined for us with great accuracy); it is therefore necessary to consider the causes and the magnitude of the error involved in each of said operations.

*First*, $w$. This can be observed with great accuracy because it is generally so small that it can be determined on a delicate balance. It is moreover practically a constant for most bodies, viz: (unaffected by oxidation, heat, etc.), so that no correction is necessary.*

* A mean of two weighings, one taken before, the other after the determination, should be used to avoid any error due to loss by oxidation, etc. Volatile liquids or substances otherwise affected by heat and contact with hot air are, of course, placed in suitable bulbs of metal or glass for the determination.

*Second*, W. This may be determined in two ways.

(*a*) By calculation from the formula

$$W = \frac{M'c' + M''c''}{c}$$

where $M'$ and $M''$ are determined by weighing, and $c'$ and $c''$ either determined by experiment (best) or taken from tables.

(*b*) By experiment in the usual manner (introducing known quantity of hot water).

Its effect on $s$ and the limiting error will be discussed under effect of M.

*Third*, M. To find the error in $s$, due to error in observing the weight, M, we have, by differentiation,

$$\frac{ds}{d(M+W)} = \frac{c(\theta - t)}{w(T-\theta)} = \frac{s}{M+W}$$

Suppose $M+W = 300$ grms. Then in order that the error of $s$ should be within 0·1 per cent, the weight must be taken to 0·3 grms.; with 200 grms. to 0·2 grm. But with the degree of accuracy ordinarily obtainable in reading temperatures to $\frac{1}{50}°$ (see below), the weight need not be taken closer than 0·5 grm. for a weight of 200 grms.; so that unless the error in observing temperatures can be reduced there is no necessity for correcting for evaporation, for loss of weight in air, etc., etc. For the same reason it is not necessary to obtain the weight of $w$ closer than ·05 grm. for a weight of 50 grms.

*Fourth*, $c$. Likewise to find $\frac{ds}{dc}$, we have $\frac{ds}{dc} = s/c$; or since $c \cong 1$, it must for an accuracy of 0·1 per cent be correct for the interval employed to ·001. But the extreme variation of $c$, for 10° (from 4° to 14° C.), is 0·00033, which makes it apparent that all correction for $c$ is entirely unnecessary, although Kohlrausch makes note of the fact that such a correction should be applied.

*Fifth. Effect of errors in observing temperatures.*

(A) Error in $t$.

From equation (2) we have

$$\frac{ds}{dt} = \Delta_t s = -\frac{(M+W)c}{w(T-\theta)} = -\frac{s}{\theta - t}. \qquad (3)$$

From the first of these values we see that in order to diminish the effect of the error in $t$ upon $s$, we must make $M+W$ as small and $T-\theta$ as large as possible, conditions which conflict with each other; for the larger $w$, and the smaller $M+W$, is, the smaller will be $T-\theta$. But the condition of things for which $\frac{M+W}{w(T-\theta)}$ will be a minimum, will evidently be $M+W = 0$, a condition which cannot be realized, but which shows

that the minimum quantity of water should always be used, so far as effects of errors in $t$ are concerned. From (3) we get directly the percentage variation of $s$ for a given error in $t$, when $\theta - t$ is known.

E. g. Suppose $\theta - t = 10°$, then $\Delta_t s = 0{\cdot}1\,\Delta t\,.\,s$. Now if we assume the maximum allowable error to be 1 in 1,000, or ·1 per cent,

$$\Delta_t s = 0{\cdot}001\,s \text{ .. and } \Delta t = 0{\cdot}01$$

or the temperature $t$ must be read to ·01 of a degree. If $\theta - t = 5°$, the temperature $t$ must be read to 1-200 of a degree. On the other hand, if $\Delta t = \frac{1}{50}°$ (and we cannot read much closer than this with a thermometer)

$\Delta_t s = 0{\cdot}002\,.\,s$ for $(\theta - t) = 10°$, an error of $\frac{1}{5}$ per cent.
$\Delta_t s = 0{\cdot}004\,.\,s$ " " $= 5°$ " " " nearly $\frac{1}{2}$ per cent.

(B) Error in T.

Errors in T may arise in three ways:

1st. By error in reading T (the *only* error which affects $t$).

2d. By the fact that the actual temperature of the body may not be that of the atmosphere which surrounds and is heating it, as indicated by the thermometer placed therein. This is avoided by keeping it surrounded for a long time with an atmosphere maintained at a constant temperature (one and one-half to four hours or more, according to the thermal conductivity of the body in question). Theoretically it would require an infinite time for complete equalization of its temperature with that of the surrounding air. The time required for equalization will be very considerably diminished by making the surface of the body as large as possible compared with its volume, or by using thin sheets of the metal or a ball of wire in place of a solid mass. This will be of advantage also in diminishing the time required for the hot body to impart its heat to the water.

3d. By the loss of heat during the time while the body is being transferred from the heating chamber to the calorimeter, which is of course diminished by making the time as short as possible, and by protecting it as well as possible during transfer.

The error of $s$ due to error in T, or $\frac{ds}{d\mathrm{T}} = \Delta_{\mathrm{T}} s$, will be

$$\left.\begin{aligned} \frac{ds}{d\mathrm{T}} = \Delta_{\mathrm{T}} s &= -\frac{(\mathrm{M}+\mathrm{W})\,c\,(\theta - t)w}{\{w(\mathrm{T}-.\,\theta)\}^2\cdot} \\ &= -\frac{c}{w.}\,\frac{(\mathrm{M}+\mathrm{W})\,(\theta - t)}{(\mathrm{T}-\theta)^2\cdot} \end{aligned}\right\} \qquad (4a)$$

$$= \frac{s}{(\mathrm{T}-\theta)} \qquad (4b)$$

From (4*a*) we see that to diminish the effect of an error in T we must, as for $t$, decrease M+W, and increase $T-\theta$, as much as possible; but that contrary to the previous case of $t$, an increase in $\theta-t$ will act injuriously. Likewise by reference to (4*b*), we see that an increase of $T-\theta$ would really be beneficial, although from (4*b*) it would seem to be in conflict with the condition that $\theta-t$ should be a minimum.

Since, however, an increase of $T-\theta$ involves an increase in M+W, and this, as we have seen in case of $t$, to be highly undesirable, it is best to decrease the value of $T-\theta$, even at the expense of an increase in the involved error of $s$, which is much less in this case than in the preceding.

If, as before, we let the maximum error of $s$ be 1 in 1,000, or 0·1 per cent, we have

When $T-\theta = 50°$, $\Delta t = 0{\cdot}05°$
" $T-\theta = 80°$, $\Delta t = 0{\cdot}08°$

Or if we read T to $\frac{1}{2}\frac{1}{5}° = 0{\cdot}04°$ the resulting error in $s$ will be less than that involved in reading $t$ to $\frac{1}{100}°$ or $\frac{1}{200}°$.

(C) We have last to consider the effect of an error in determining $\theta$. This is the most important of the errors in the temperature readings, both because of its effect upon $s$, and the numerous causes which go to produce it, combined with the difficulty of guarding against them.

1st. The error produced in $s$ will be found as before, by differentiating (2).

$$\left.\begin{aligned}\frac{ds}{d\theta} = \Delta_\theta s &= \frac{(M+W)\,c\,(T-\theta)+(M+W)\,c\,(\theta-t)}{w(T-\theta)^2} \\ &= \frac{c}{w}\cdot\frac{(M+W)}{(T-\theta)} + \frac{c}{w}\,\frac{(M+W)\,(\theta-t)}{(T-\theta)^2}\end{aligned}\right\} \quad (5a)$$

$$= \frac{s}{\theta-t} + \frac{s}{T-\theta} \quad (5b)$$

thus involving both corrections already found. Here, since the first correction is generally larger than the second, the most desirable thing to do will be to increase $\theta-t$ (by decreasing M+W), rather than to increase $T-\theta$, except by increasing T, which in most forms of heating apparatus has its limit at 100° C.

If as before, we take the maximum allowable error as 0·1 per cent, we have

For $\theta-t = 10°$ and $T-\theta = 50°$, $\Delta\theta = 0{\cdot}0083° \cong \frac{1}{120}°$
" $\theta-t = 5°$ " $T-\theta = 80°$, $\Delta\theta = 0{\cdot}0047° \cong \frac{1}{212}°$

Conversely, if we read $\theta$ to only $\frac{1}{50}°$ we get

$\Delta_\theta s = 0{\cdot}0024 = \frac{1}{4}$ of one per cent for the 1st case.
$\Delta_\theta s = 0{\cdot}00425 = \frac{8}{5}+$ " " " " " 2d case.

2d. There is another class of errors in $\theta$, not due to errors of reading, but which are even more important than these, viz: errors due to $\theta$ never reaching its maximum value required by theory because of the heat received or lost by radiation. Hence $\theta_n$, as observed, will not be the true value suitable for use in (2), but some value lower than this; unless indeed, we start with a temperature so low that the final temperature $\theta$ is less than that of the air; in which case $\theta_n$ will be too high. To eliminate this error, due to radiation, several methods have been proposed.

(*a*) Those methods which take account of the temperature of the external air.

The simplest of these is that of Rumford (compensation method). This is to determine by preliminary calculations the rise of temperature in the calorimeter while the body is cooling and make the initial temperature of the water as much lower than that of the surrounding air as the final temperature is higher. The fallacy of this method lies in the fact that the time required for the last part of the operation is much longer than that required for the first. If we make the initial temperature of the water $\frac{2}{3}(\theta - t)$ lower than the external air, we will come nearer to "compensating" for radiation.

(*b*) Methods of Jamin and Regnault.

Both of these methods depend on a series of observations begun four or five minutes before and continued as long after the introduction of the heated body into the calorimeter. Radiation is proportional to three factors,—time, excess of temperature, and surface. For any given calorimeter, then, the loss per unit of time is a constant $\times(\theta - \beta)$, where $\beta$ is the temperature of external air or calorimeter jacket. The lowering of temperature due to this loss is, therefore, A $(\theta - \beta)$, during each unit of time for which $\theta - \beta$ is the mean excess of temperature.

Let a series of readings be taken at intervals $x_1$, $x_2$, $x_3$, $x_4$, $x_5$, etc., from the instant of immersion to the time when the reading of the thermometer becomes steady, giving a series of temperatures $\theta_1$, $\theta_2$, $\theta_3$, $\theta_4$, etc. Then during the intervals $x_2 - x_1$, $x_3 - x_2$, etc., the mean excess of temperature is

$$\frac{\theta_2 + \theta_1}{2} - \beta, \quad \frac{\theta_2 + \theta_3}{2} - \beta, \text{ etc.}$$

And the loss of temperature then is

$$\Delta_1\theta = \left(\frac{\theta_2 + \theta_1}{2} - \beta\right)(x_2 - x_1)\mathrm{A}$$

for the interval $(x_2 - x_1)$

$$\Delta_2\theta = \left(\frac{\theta_3 + \theta_2}{2} - \beta\right)(x_3 - x_2)\mathrm{A}$$

for the interval $(x_3 - x_2)$, etc., etc.

Then if we take the algebraic sum of these variations we obtain $\Sigma\Delta\theta$ as the total correction for the observed temperature $\theta_n$ at the end of the experiment, which added to this observed temperature gives the correct value of $\theta$ to use in formula (2). This method requires us to know both the temperature of the external air and the quantity A. The first is known from observation; the second can be determined from the formula for loss of heat by radiation, which is given on p. 91, vol. i (Jamin's Physique), as

$$\text{Q} = \text{loss of heat per sec} = \frac{1}{4000}\, k\text{S}(\theta-\beta)$$

hence $\Delta\theta =$ " temp. " $= \frac{1}{4000}\,\frac{k\text{S}(\theta-\beta)}{(\text{M}+\text{W})c}$

where

S.. is the surface of the calorimeter.
$k$.. " value of a (small) calorie.

Hence

$$\text{A} = \cdot 00025\,\frac{\text{S}}{\text{M}+\text{W}} \quad * \qquad (6)$$

$c$ being taken as unity.

*Method of Regnault.*†—To render the observation of the external temperature (a temperature always hard to determine with accuracy) unnecessary, the readings are taken at intervals as before, but commenced before and extended after the time during which equalization is taking place. The whole operation comprises three periods, the first a short period just before the introduction of the body; the second beginning with the introduction of the body into the calorimeter and ending with the maximum temperature; the third, during which a few additional observations are made on the rate of cooling. Let $x$ be the interval between successive readings, $a$, $n$, and $b$ the number of readings in the three periods respectively, and $\theta_0$, $\theta_1$, $\theta_2 \ldots$ to $\theta_n$, the readings of the thermometer during the second period, the body being introduced at the beginning of the $a+1$nth interval, $(\theta=\theta_0)$. Also let $t_1$, $t_2$ equal the mean temperatures during the first and third periods, and $\Delta_1$, $\Delta_2$ the mean loss of temperature for these periods for the time, $x$, and let $\theta_{m'}=\frac{\theta_0+\theta_1}{2}$, $\theta_{m''}=\frac{\theta_1+\theta_2}{2}$, etc., and $\Delta_2'$, $\Delta_2''$, etc., be the mean temperatures and corresponding losses of temperature due to radiation during the successive intervals of the middle period.

* The value of the constant term in this formula will of course depend on the nature of the radiating surface of the calorimeter.

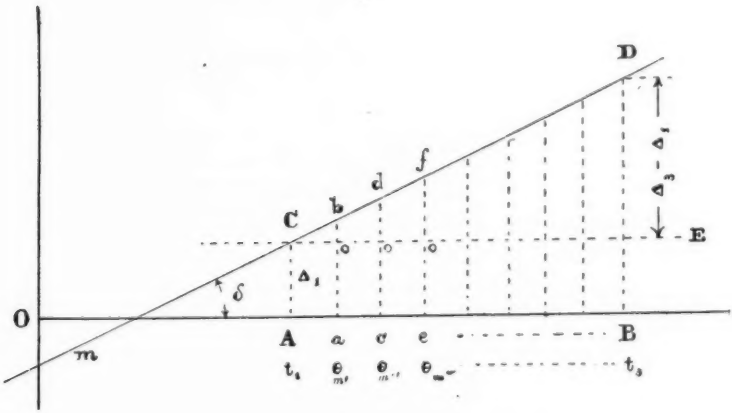
† This method of correction is essentially that described in Professor Holman's paper, in which a somewhat different method of reduction is adopted.

Then the maximum observed temperature $\theta_n$ at the end of the second period will be less than the true maximum by an amount $\Delta\theta=\sum_1^n \Delta_2$. To determine this quantity we make use of the same principle as before, viz: that the loss of temperature is proportional to the difference of temperature between the calorimeter and external air, or

$$\left.\begin{aligned}\Delta&=\kappa(t-\beta)\\ &=\kappa t-C\end{aligned}\right\} \qquad (7)$$

the equation of straight line cutting the $\Delta$ axis at a point, $-C$, from the origin.

1.




The observations just given furnish data for drawing the line of which (7) is the equation. Thus in fig. 1 lay off $OA=t_1$, the mean temperature for the first interval, and AC, proportional to $\Delta_1$, the mean loss per interval, $\varkappa$, for same period; likewise lay off $OB=t_3$, the mean temperature for the third interval, and BD, proportional to $\Delta_3$, the corresponding mean loss. Draw through D, C, the straight line DCm; this will be the line required. Then it is evident that for any other temperature, as some temperature $\theta_m$ during the second interval, the loss, $\Delta_2$, will be the ordinate to this line at a point whose abscissa is $\theta_m$. The total loss during the whole of the interval $=\Sigma\Delta_2$. This summation may be effected by a formula derived from inspection of fig. 1. For

$$\begin{aligned}\sum_1^n \Delta_2&=\Delta_2'+\Delta_2''+\ldots\ldots\ldots+\Delta_2^n\\ &=ab+cd+fe+\ldots\ldots+\text{ordinate at } \theta_{m^n}\end{aligned}$$

Draw CE parallel to axis of $t$. Then

$ab=ao+ob$; $cd=co+od$, etc., etc.

$$\therefore \sum_1^n \Delta_2 = n(ao)+bo+do+\ldots\ldots \quad +no$$

$$= n\Delta_1 + \text{tang}\,\delta\{\theta_{m'}-t_1+\theta_{m''}-t_1+\ldots\ldots\ldots+\theta_{m^n}-t_1\}$$

$$= n\Delta_1 + \text{tang}\,\delta\left\{\frac{\theta_0+\theta_1}{2}-t_1+\frac{\theta_1+\theta_2}{2}-t_1+\ldots\ldots+\frac{\theta_{n-1}+\theta_n}{2}-t_1\right\}$$

$$= n\Delta_1 + \text{tang}\,\delta\left\{\sum_1^{n-1}\theta+\frac{\theta_0+\theta_n}{2}-nt_1\right\}$$

Then to find tang $\delta$ we have

$$\text{tang}\,\delta=\frac{\Delta_2-\Delta_1}{t_2-t_1} \qquad \text{(from fig. 1)}$$

or as a final result

$$\sum_1^n \Delta_2 = n\Delta_1 + \frac{\Delta_2-\Delta_1}{t_2-t_1}\left\{\sum_1^{n-1}\theta+\frac{\theta_0+\theta_n}{2}-nt_1\right\} \qquad (8)$$

and true temperature after equalization will be

$$\theta=\theta_n+\sum_1^n \Delta_2$$

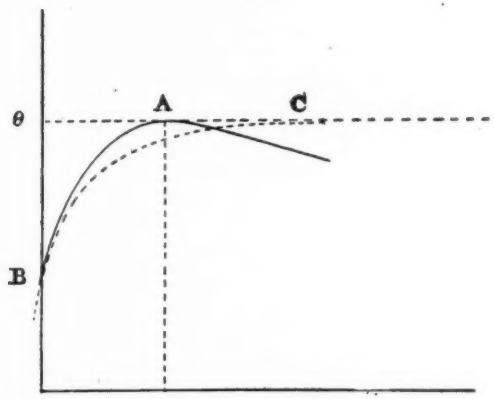
Other precautions which are of advantage will be readily noted by observing that loss by radiation depends upon three factors: 1st, excess of temperature of calorimeter above the temperature of the surrounding air. This excess will be diminished by making the mass of water M large, so that the rise in temperature, $\theta-t$, will be small. This cannot be carried too far, however, because when the interval becomes small the difficulty of reading temperature to the required degree of accuracy is greatly increased (see 5A and 5C). 2d, surface exposed. Theoretically the best form of calorimeter vessel would be a sphere; but as that is difficult of construction the next best form is that of a cylinder of maximum capacity per superficial area, viz: one in which the altitude equals the diameter of the base. 3d, time. The time element will be reduced by keeping the water well agitated and by using the body in the form of flat strips or wires rolled up into a ball instead of a solid mass.

Finally, there is an error in the observed temperature due to the thermometer itself, which, when its stem is exposed to a temperature below that of the bulb, indicates a lower reading than it should. This error can only be determined in any given case by careful experimental observations of the "time lag" and "stem lag" of the thermometer. To make it as small as possible, the thermometer should be of the smallest possible size, and immersed so deeply in the calorimeter that only enough of the stem projects to make the readings possible.

A better arrangement for observing both the temperature T and the temperature $\theta$ would be thermo-elements placed respectively in the heating chamber and in the calorimeter.*

(*c*) *New Method.*—Returning now to the method of Rumford, it is evident that we might indeed find such a value for the external temperature that the maximum reading $\theta_n$ would be the same as though there were no radiation. Thus in the figure below (fig. 1a), if we let the ordinates represent temperature and the abscissas time, we have, when no radiation takes place, the curve BC, whose equation is of the general form $x=f(\log\theta)$. Hence the maximum $\theta$ is *never* reached. When we consider radiation, however, we find that the curve BA will, when $\beta$ has a certain value between $t$ and $\theta$ ($\beta$ being as before the temperature of the air), reach a true maximum at A, which is equal to the theoretical maximum $\theta$. At this point the heat imparted to the water from the body just equals the heat lost by radiation.

1a.




The heat lost by radiation, $dq_r = AS(\theta-\beta)dx$ (9)

The heat gained from the body, $dq_s = \frac{1}{\sigma}S_1(T_0-\theta)dx$ (10)

where $\sigma$ is the coëfficient of external thermal resistance; S

* A still more promising method of observing temperatures is the use of the platinum thermometer recently brought to such a degree of perfection by the work of Callendar. Either this, or the thermo-element (now immensely improved by the work of Barus and others), ought on account of its small mass, rapid response to change of temperature, and sensitiveness, to be far better adapted to accurate calorimetric work than the mercurial thermometer now so commonly employed. About the only advantage of the latter is its simplicity and cheapness,—qualifications which determine its use in ordinary laboratory work, but have far less importance in accurate research work.

and $S_1$ the surfaces of the calorimeter and the body respectively, and $T_0$, the temperature of the cooling body. In general $\sigma$ is itself a function of $T - \theta$ (see Rankine's Treatise on the Steam Engine, p. 260). Thus for a plate of thickness $y$ and thermal resistance $\rho$ immersed in a liquid the flow of heat through the plate is $\frac{1}{2\rho}.\frac{T_x - T_x'}{y}.S_1 dx$; $T_x$ and $T_x'$ being the temperatures of the two sides of the plate. The flow of heat from the liquid of temperature $\theta_x$ into the plate on one side is $\frac{1}{2\sigma}(T_x - \theta_x)S_1 dx$, and from the plate into the liquid on the other is $\frac{1}{2\sigma}(T_x' - \theta_x)S_1 dx$. If the temperature is uniform throughout the plate, i. e. if $T_x - T_x'$ is zero, as will be practically true if the thermal resistance $\rho$ is very small compared to the external resistance $\sigma$, we get for the total flow of heat from the plate into the liquid at the time, $x$,

$$dq_x = \frac{1}{\sigma}S_1(T_x - \theta_x)dx = -wsdT \qquad (11)$$

But from Peclet's formula

$$\sigma + \sigma_1 = \frac{1}{K\{1 + B(T_x - \theta_x)\}}$$

here

$$\sigma = \sigma_1$$

hence

$$\frac{1}{\sigma} = 2K\{1 + B(T_x - \theta_x)\}$$

Substituting in (11) we get

$$dq_x = (T_x - \theta_x)2K\{1 + B(T_x - \theta_x)\}S_1 dx = -wsdT \qquad (12)$$

and at maximum (9)=(10)=(12), or

$$AS(\theta - \beta) = 2KS_1(T_0 - \theta) + 2KBS_1(T_0 - \theta)^2 \qquad (13)$$

Hence if we determine $T_0$, all the quantities being known except $\beta$, this last may be readily calculated.

The determination of $T_0$ is attended with some difficulties, which may be avoided by expressing $T_0$ as a function of the time $x_0$ required for the contents of the calorimeter to acquire the maximum temperature $\theta$.

The total heat imparted to the water of the calorimeter consists of two parts:

1st. Heat taken from body

$$= (T - T_0)ws, \quad \text{at time } x_0 \qquad (14)$$

2d. Heat taken from air

$$= \mathrm{AS}\int_0^{x_0} (\theta_x - \beta)dx \qquad (15)$$

and since the heat contained in the water is the same at maximum point $\theta$ (by assumption) as though all the heat from the body had been communicated to it and no radiation had taken place, we have at the time, $x_0$, of maximum

$$(\mathrm{T}_0 - \theta)ws = \mathrm{AS}\int_0^{x_0} (\theta_x - \beta)dx \ * \qquad (16)$$

or in general at any time, $x$, from the instant of immersion

$$(\mathrm{T} - \mathrm{T}_x)ws = (\theta_x - t)(\mathrm{M} + \mathrm{W})c + \mathrm{AS}\int_0^{x} (\theta_x - \beta)dx \qquad (17)$$

To find an approximate value of $\mathrm{T}_x - \theta_x$ for substitution in (12) we may neglect the last term as small compared with the others, and write

$$(\mathrm{T} - \mathrm{T}_x)ws = (\theta_x - t)\ (\mathrm{M} + \mathrm{W})c$$

whence

$$(\mathrm{T}_x - \theta_x) = \mathrm{T}_x\left(1 + \frac{ws}{(\mathrm{M}+\mathrm{W})c}\right) - \left(\mathrm{T}\frac{ws}{(\mathrm{M}+\mathrm{W})c} + t\right) = b\mathrm{T}_x - a \qquad (18)$$

Then substituting in (12), we get

$$-ws\frac{d\mathrm{T}}{dx} = 2\mathrm{KS}_1(b\mathrm{T}_x - a) + 2\mathrm{KBS}_1(b\mathrm{T}_x - a)^2$$

Integrating we get

$$x\Big]_0^{x_0} = -\frac{ws}{2b\mathrm{KS}_1}\left[\log\frac{b\mathrm{T}_x - a}{2\mathrm{KS}_1 + 2\mathrm{KBS}_1(b\mathrm{T}_x - a)}\right]_{\mathrm{T}}^{\mathrm{T}_0}$$

or

$$x_0 = \frac{ws}{2b\mathrm{KS}_1}\log\left\{\frac{b\mathrm{T} - a}{b\mathrm{T}_0 - a}\cdot\frac{1 + \mathrm{B}(b\mathrm{T}_0 - a)}{1 + \mathrm{B}(b\mathrm{T} - a)}\right. \qquad (19)$$

or

$$e^{\frac{2b\mathrm{KS}_1}{ws}x_0} = \frac{b\mathrm{T} - a}{b\mathrm{T}_0 - a}\cdot\frac{1 + \mathrm{B}(b\mathrm{T}_0 - a)}{1 + \mathrm{B}(b\mathrm{T} - a)} \qquad (20)$$

Then solving for $\mathrm{T}_0$ we find

$$\mathrm{T}_0 = \frac{a}{b} + \frac{b\mathrm{T} - a}{b\{e^n[1 + \mathrm{B}(b\mathrm{T} - a)\ ] - \mathrm{B}(\mathrm{T} - t)\}}$$

$$= \theta + \frac{\mathrm{T} - t}{b\{e^n + \mathrm{B}(e^n - 1)\ (\mathrm{T} - t)\}} \qquad (21)$$

* It may be observed that the value of the integral in the second member of this equation is not necessarily zero. In other words the conditions (value of $\beta$, etc.), which give the proper value of $\theta$ for use in equation (2) are not such as to make the total loss of heat by radiation zero, as assumed by Rumford.

where

$$R = \frac{2bKS_1}{ws} x_0$$

In this equation all the quantities are known, at least approximately, or may be observed or calculated except K, B, and $T_0$. The values of the constants K and B for metal plates in contact with water are, according to Peclet (Rankine, p. 260),

$$K = \cdot 00119$$
$$B = \cdot 1044$$

I have not been able to find the data upon which these values are based. They will of course vary with the condition and nature of the cooling surface and will be larger when the water is well stirred than when it is not. The best way is to determine them, for the given body and given calorimeter, by a series of preliminary observations on $x_0$, the time required for $\theta_x$ to attain its maximum value, $\theta$. In making these observations, $t$ should be made about $\frac{2}{3}(\theta - t)$ lower than $\beta$, the temperature of the surrounding air. Three such preliminary observations (made in the same way as they would ordinarily be made to determine $s$) would suffice (though a larger number reduced by the method of Least Squares would be better) to determine K, B, and $T_0$, this last quantity as determined from (21) being practically the same (for such rapid cooling as always takes place in a properly conducted calorimetric experiment) as that which would be determined from the theoretically correct but far more complicated expression (17). Having thus found $T_0$, we may then find a first approximation to the value of $\beta$ from (13); A, the radiation factor of the calorimeter being taken as given by Jamin, or better determined for each calorimeter by experiment.

With this value of $\beta$ a second set of observations are taken for $x_0$ and with this new value a second and closer value of $\beta$ determined as before. Two such successive approximations will suffice to determine $\beta$ with the desired accuracy.

The use of this method renders any precautions for preventing radiation useless. All that is necessary is to keep the temperature of the surrounding air uniform, and at the determined temperature (practically this is best done by adjusting the initial temperature $t$ of the calorimeter contents), and keep the water in the calorimeter well agitated during the progress of the experiment, while screening the calorimeter from direct radiation from the observer's body. Then the maximum temperature attained will be the theoretical maximum, $\theta$, desired, and radiation, instead of being a disadvantage, will become an advantage inasmuch as it lessens the time of the experiment

and makes the maximum more sharply defined. The greatest drawback to the use of this method is the preliminary labor of observing for and computing $T_0$ and $\beta$. But this preliminary labor is well worth while, when the highest degree of accuracy is aimed at.

*Conclusion.*—It appears then from the preceding discussion that the greatest possible care should be taken in reading temperatures, and since the errors of these readings are much greater than any others likely to be committed, it is advisable, in order to minimize the effect of these errors, to use

1. A small amount of water in the calorimeter; i. e., a small calorimeter.

2. A large mass of metal having a maximum surface for given weight (sheets or wire);

3. As high an initial temperature, T, as can be conveniently attained.

4. The calorimeter should be surrounded by a water jacket maintained at a constant temperature $\beta$, higher than the initial temperature $t$ of the water in the calorimeter by the amount determined by (21) and (13).

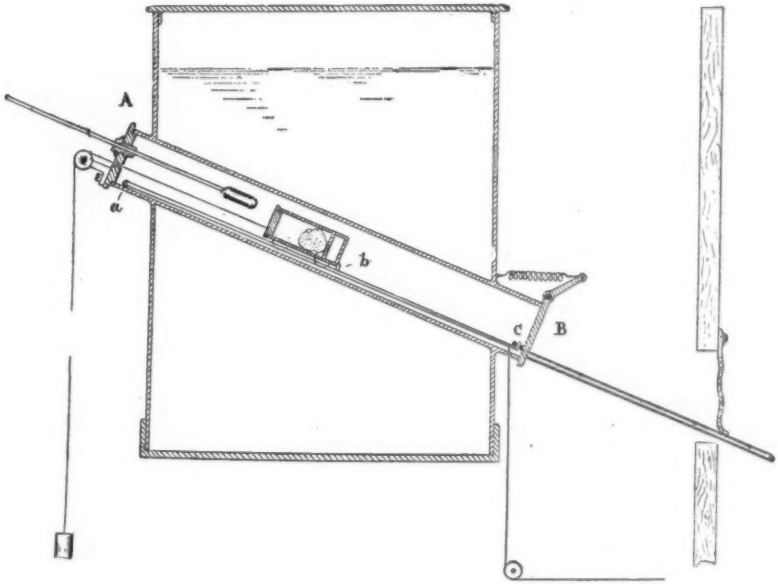
Physical Laboratory, Ohio State University,
December, 1888.

## NOTES ON CALORIMETRY.

The ordinary method of transferring the hot body from the heating chamber to the calorimeter by allowing it to slide down and out of an inclined tube into the mouth of the calorimeter is open to a number of objections, chief among which is the loss of heat in passing through the air, the loss of water by splashing, etc., and more important than all else, the loss of time in moving the calorimeter up to and away from the heating chamber, and in uncovering and covering the calorimeter at the most critical stage of the operation, when the attention of the observer should be entirely directed to the reading of temperatures, and disturbing influences should be reduced to a minimum. To avoid these difficulties I devised some time ago the arrangement shown in fig. 2. The tube, which forms the heating chamber of a Regnault apparatus, is removed and replaced in a more nearly horizontal position, A, B, fig. 2. A track consisting of two parallel steel wires, tied together at intervals, is laid along the bottom of this tube and continues for some distance beyond the lower end. On this track rolls a square (or cylindrical) double-walled car of sheet copper, mounted on four wheels, two (on one side) with grooved faces, and two (on the other side) with straight faces. In this car is placed, just over a trap door at the forward end, the object whose specific heat is to be determined. When the latter is being heated the car containing it is drawn up into the

heating tube by a silk cord passing over a pulley, and held taut by a mass attached to the free end, whose weight is somewhat less than the component weight along the track, of car and body together, and somewhat greater than that of car alone. The

2.

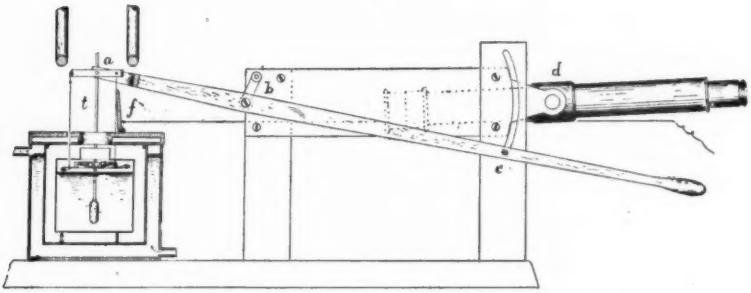



car is held in position by a pin *b*, on the steel wire *abc*, which is pivoted at *a* between the rails of the track. A second pin *c* at the lower end of this wire enters a catch on the inside of the door B at the lower end of the heating tube and holds it closed against the tension of a coiled spring.

The calorimeter itself is placed under the lower end of the track (six or eight feet distant from the heating chamber) and consists as shown in section in fig. 3 (taken at right angles to the section of the heating chamber fig. 2), of an inner copper chamber which differs from that ordinarily used in being much shorter (diameter=height) and in having a tightly fitting bottle-shaped top, the opening in which is just large enough to admit the heated body. Just under this opening is a wire basket with attached copper paddles, which is hung on three light brass wires, passing freely through tubular holes at the sides of the neck of the opening and on up through the outer double cover of the calorimeter. They are attached above by

hooks to a light brass ring, which in turn is pivoted in the forked end of a long wooden lever *a*, *b*, *c*. This lever is hung on a link at *b* and has a pin at *c* which moves in a slot cut in a plate of brass or hard wood of such shape that *a* moves up

3.




and down in a straight line. The end *c* is so weighted as to slightly overbalance the ring, bracket, etc., hung on the other end. The thermometer, *t*, is read by means of a very short focus telescope, made by slipping over the end of an ordinary reading telescope, a cap carrying a second object glass of about the same focal length as that of the telescope. It is balanced on pivots, *d*, so as to easily follow the movement of the mercury column. The inner calorimeter, which is filled with water almost up to the neck, is completely enclosed in a water jacket whose inner walls are blackened (not left bright as usual). The cover is double, of heavy sheet metal, and the hole in the center through which the body drops into the inner calorimeter has a hinged trap door, *f*, which can be turned back against a step on the calorimeter cover. When a good water supply is available, I have found that the temperature of this water jacket is most easily kept constant by allowing a slow constant stream to flow through it from bottom to top, from a large tank supplied from the city (or building) mains.

The method of introducing the hot body into the calorimeter is almost self-explanatory from what has preceded. The observer at the eye end of the telescope pulls open by aid of a string the trap door in the top of the water jacket, and then by means of a second string pulls down the end of the wire, *ac* (fig. 2), releasing the car and the door, B, at the same instant. The car runs rapidly down the track, throwing aside in its course the flaps of woolen cloth which cover the openings in the interposed wooden screens (see fig. 2), and is brought to rest by a rubber buffer which stops it in such a

position that the trap door in the bottom of the car is just over that in the water jacket. A pin fixed in proper position on the track knocks away the catch on the trap door of the car just as the latter comes to rest, and the body falls into the basket (which is held at its highest point by the overweight on the end *c* of the lever), precipitating the latter, both by its momentum and weight, downward into the water in the calorimeter. As the lever goes down the observer lets go the string which holds the trap door *f* open, and it also closes. The car, relieved of the weight of *w*, is pulled back out of the way by the attached weight. The observer himself has then only to observe temperatures while keeping the water in constant and complete agitation by moving the end *c* of the lever up and down.

The calorimeter is readily removed when temperature observations have been completed, by unhooking the wires, sliding the water jacket to one side from under the track, and lifting off the cover of the latter. The thermometer and wire basket remain in the calorimeter vessel, and are weighed with it, thus avoiding any loss of water, etc., consequent upon their removal.

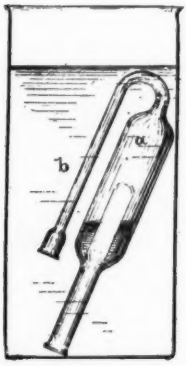
This apparatus, although it may seem at first sight complicated, is in reality very simple, and readily put together by any one having a small shop in his laboratory, in one or two days. The great advantage resulting from its use will be readily appreciated. It enables, in the first place, one observer to do all the work of observation, although it is convenient to have some one to write down the thermometer readings. The use of the wire basket to catch the hot body, rather than allowing it to fall directly into the calorimeter, has three advantages: (1) it prevents splashing the water, and therefore allows the calorimeter to be filled nearly full, thus obtaining a maximum volume with a minimum of radiating surface; (2) it allows of a more thorough agitation of the water, the body itself being moved through it, and hence a more rapid equalization of temperature in the calorimeter; (3) it prevents any danger of breaking the thermometer bulb or injuring the sides or bottom of the calorimeter when a heavy body is dropped into it.

The use of the car to transfer the body from the heating chamber to the calorimeter not only prevents a loss of heat during the transfer, but also enables a number of small fragments, or even a mass of powder of the substance, to be used without the necessity of using an enclosing bulb, a device which always renders the equalization process slower and more uncertain.

*Notes on the Bunsen Ice Calorimeter.*

*Filling.*—More or less elaborate directions are generally given for filling the body of the calorimeter with water and mercury. The following process, which I have used for some time, is very simple, direct and efficient. The required quantity of mercury is first poured into the calorimeter through a small glass funnel, whose stem has been drawn out into a long, fine bulb, which will reach to the bottom of the side tube *b*, of the calorimeter. The calorimeter is then inverted in a beaker of distilled water deep enough to cover it to above the bend of the side tube, as in fig. 4. The mercury already introduced, which is now in the upper part of the water chamber, will hold the calorimeter down under the water. The beaker containing the water is now heated to boiling and cooled. When the calorimeter chamber *a* has been partly filled with water by the cooling, the whole is raised to boiling again, and kept at that temperature until all the air in *a* has been replaced by steam. On cooling again *a* will be completely filled with hot, air free, water. When cool enough to handle, the finger is placed over the mouth of *b* and the calorimeter removed from the water and turned into the upright position. The mercury will run down to the bottom of *a*, leaving, however, some water still in *b*. This is then displaced by more mercury introduced through a funnel as before.

4.




*Maintaining at Zero Temperature.*—In using the ice calorimeter it is necessary, as has been pointed out by Bunsen, to have the calorimeter surrounded by *pure* melting ice or snow of exactly zero temperature. Since perfectly pure ice or snow is difficult to obtain, it occurred to the writer some time ago that the most convenient way of securing the desired result would be to immerse the calorimeter in a vessel (a wide-mouthed bottle has proved very convenient in practice) filled with distilled water, and freeze a shell of pure ice on the inside of this bottle by placing it in a freezing mixture, leaving a space between ice and calorimeter filled with pure distilled water. When this has been done the whole arrangement is then placed in a larger vessel filled with ordinary crushed ice or snow. If this is not exactly at zero temperature (owing to impurities) the only result will be to cause a slow progressive freezing or thawing in the ice shell of the inner vessel. The distilled water being in contact with pure ice will, if occasionally stirred, remain at zero temperature.

Yerkes Observatory, June, 1897.

ART. XXXI.—*The systematic position of Crangopsis vermiformis (Meek), from the Subcarboniferous rocks of Kentucky;* by ARNOLD E. ORTMANN, Ph.D.

IN 1872 and 1875 F. B. Meek described* a peculiar Crustacean from the lowermost Subcarboniferous rocks (base of Waverly series) near Danville, Ky., under the name of *Archæocaris vermiformis*, but owing to the imperfect condition of his specimens he did not express any opinion as to the systematic position of this fossil. The Museum of Geology of Princeton University possesses quite a number of specimens of this form, which were collected by M. Fischer at or near the same locality (Boyle Co., Ky.), and which are also for the most part poorly preserved. Yet a few specimens are better, and one of them shows clearly a peculiar feature which enables us to make out its approximate systematic position.

Previously, Crustacean remains closely resembling Meek's species have been reported by Salter† from the Subcarboniferous (Mountain Limestone) of Scotland under the name *Palæocrangon socialis*, the generic name being subsequently changed into *Crangopsis* Salter,‡ in order to prevent confusion with *Palæocrangon* Schauroth. Salter places his fossils among the Macrurous Decapods, considering the presence of a carapace, of seven distinct abdominal segments, and of caudal swimmerts as conclusive. These three characters are all that is known of *Crangopsis*, and *Archæocaris* of Meek shows exactly the same; there is nothing that should induce us to separate generically the American from the Scotch fossil. Accordingly, we should consider *Archæocaris* as a synonym of *Crangopsis*, and the American species should be called *Crangopsis vermiformis* (Meek). The three characters which induced Salter to place his genus among the Decapods are not sufficient to warrant the correctness of this position. On the contrary, these three characters are present, among the Malacostraca, in the same combination also in the living orders of the *Stomatopoda*, *Euphausiacea*, and *Mysidacea*,§ and we cannot make out the proper position of these fossils according to our present knowledge. From one specimen however in the Princeton collection (Mus. No. 1597[c]) we learn another very important character.

* Proc. Acad. Philad., 1872, p. 335; Geol. Surv. Ohio, Palæont., ii, 1875, p. 321, pl. 18, fig. 1.

† Trans. Roy. Soc. Edinburgh, xxii, p. 394; Quart. Journ. Geol. Soc. London, xvii, 1861, p. 533, fig. 8.

‡ See Zittel, Handb. Palæont., ii, 1885, p. 682.

§ Compare Boas, in Morpholog. Jahrb., viii, 1883.

Of this specimen the body is complete, showing the carapace and the whole abdomen preserved *in situ*. Fortunately, the hinder and upper part of the carapace is broken away, thus enabling us to see that in addition to the seven abdominal segments exposed in specimens with unbroken carapace, there are, in front of them, *four* other segments present, originally covered by the hinder expansion of the carapace, and these four (thoracic) segments are dorsally perfectly closed, smooth, and uninjured, thus proving that they were not connected and anchylosed with the carapace, but free dorsally. These free thoracic segments are exhibited in a few other specimens (Mus. No. 1597[d]), but since in the latter the abdomen is not complete, their exact number cannot be determined.

This character clearly shows that *Crangopsis vermiformis* cannot be a *Decapod*. In the Decapods all the thoracic segments are firmly united dorsally with the carapace. Neither can *Crangopsis* belong to the *Euphausiacea*, because in this order only the last (fifth) thoracic segment is dorsally free, while all the others are united with the carapace. In the *Stomatopoda* the five thoracic segments are free, but they are not covered by the carapace; only in the *Mysidacea* we have the same condition as shown by *Crangopsis*. Thus, according to this character, this genus should be placed in the order of *Mysidacea*, and it is the *first fossil form* assigned to this group.

I think, however, it would be a little rash to assume positively that *Crangopsis* belongs to that group of *recent* animals designated as the order *Mysidacea*, since we know nothing of the other characters of this form. It is true, the character mentioned is present, among the living Malacostraca, only in the order of *Mysidacea*, but it is a mere secondary one, the principal characters being drawn from the differentiation of the appendages of the body. In the fossil *Crangopsis* only faint traces of limbs have been discovered, but their number, their shape and differentiation are entirely unknown, and accordingly we are at a loss to recognize the typical characters of any particular order of the Malacostraca; we may even imagine that *Crangopsis* possessed in the conformation of the thorax the characters of Mysidacea, while the limbs were developed according to the Decapod-type, a condition which is not altogether impossible. Since *Crangopsis* belongs to the earliest forms of Malacostraca, we are to expect that it belongs to a primitive group, perhaps to that group which forms the original stock from which all the now living Malacostraca originated. But the presence of a carapace covering entirely the thorax indicates that this genus belongs to the *Thoracostraca*, and further, the fact that the four last thoracic segments are dor-

sally free, shows that closer relations exist to the *Mysidacea* than to any other order.

There is no doubt that the Carboniferous and Permian fossils designated by Brocchi* as a new family (*Nectotelsonidæ*) of the order Amphipoda belong to that primitive group of Malacostraca which gave origin to the different now living orders. This family contains the genera *Palæocaris* Meek and Worthen, *Uronectes* Bronn (= *Gampsonyx* Jordan), and *Nectotelson* Brocchi, but its position among the Amphipods, as maintained by Brocchi, is certainly erroneous. The *Nectotelsonidæ* show a number of characters common to all Malacostraca, but no typical characters of any of the orders of this subclass; they represent a mere collective type of different Malacostracous orders.

The general characters of all Malacostraca are the following: Body with a limited number of segments; the number of the anterior segment is somewhat doubtful, but there are certainly eight segments of the "cormus" bearing the cormopods, and seven of the abdomen or pleon, six of which bear pleopods, the last one forming with the telson a caudal fin. A differentiation between the appendages of the cormus and the pleon is present. This primitive type of Malacostraca is divided into two large sections: the *Thoracostraca*, having a carapace developed and stalked eyes, and the *Arthrostraca* having no carapace and sessile eyes.† The first section is farther characterized by the prevailing presence of the caudal fin (which is reduced only in the Decapoda Brachyura); of the second section only a part of the Isopods retains the caudal fin. In the Thoracostraca the legs are either differentiated in the primitive manner into cormopods and pleopods, or the former are again divided (Decapoda) into three maxillipeds and five pereiopods (thoracic legs). In the Arthrostraca, there is never a differentiation of maxillipeds and pereiopods, but often (Amphipoda) the pleopods are divided into swimming (anterior) and jumping (posterior) feet.

The *Nectotelsonidæ* of Brocchi show on the one hand the primitive characters of the Malacostraca; they have a limited number of body-segments, divided according to the appendages into a cormus and a pleon with a caudal fin. On the other hand no carapace is developed and stalked eyes are present.‡ The latter character, and the shape of the antennæ, and the gill-like appendages on the bases of the cormopods separate this group from the Arthrostraca, and Jordan and Meyer were perfectly right in so far as giving *Uronectes* a position inter-

* Bull. Soc. Geol. France, iii, 8, 1880.

† I disregard the *Cumacea*, which are intermediate between both in this respect.

‡ The details of structure given here are best known in *Uronectes* (= *Gampsonyx*). Compare Jordan and Meyer, Palæontographica, iv, 1, 1854, p. 1, ff. pl. 1.

mediate between the Arthrostraca and Thoracostraca: but in pointing to the resemblance to the Amphipods they were wrong, since there are no closer relations present to that order. The other genera referred by Brocchi to the *Nectotelsonidæ* are only incompletely known, but their general appearance strongly favors the opinion that they really belong to the relatives of *Uronectes*. The description of the genus *Nectotelson* of the Permian of Autun, France, is very poor and contradictory. Brocchi gives it seven thoracic segments (p. 6) and four abdominal segments, but his figures show nothing that might warrant this number, and fig. 1 (pl. 1), indeed, shows clearly that the number *four* for the abdominal segments is incorrect. Further, he says (p. 7) that probably the eyes were small and sessile: but the specimens did not show any traces of these organs! He did not discover in his specimens an appendage of the antennæ: these characters and the much smaller size are the only differences of Nectotelson and Uronectes. The limbs of Nectotelson (pl. 1, fig. 2) are badly preserved, but they resemble apparently those of Uronectes.*

As regards the genera *Palæocaris* and *Acanthotelson* of Meek and Worthen,† I refer only to the descriptions and restorations given by Packard‡ from which it is apparent that both are closely related to *Uronectes*.

In order to get an approximate idea of the systematic position of Brocchi's *Nectotelsonidæ*, we may rely upon a combination of the characters of these three or four genera, and if we consider these characters as conclusive for this family, we may say that the *Nectotelsonidæ* show the typical characters of the subclassis Malacostraca; but further on they unite characters of the Arthrostraca (the missing carapace) with those of the Thoracostraca (stalked eyes), thus proving to be a primitive group from which the former as well as the latter might be derived.

I may add here that Packard creates the *suborder Syncarida* for these genera,§ which thus consists of Brocchi's *family Nectotelsonidæ*.

* It is astonishing that Brocchi in comparing Nectotelson with Uronectes did not consult the paper of Jordan and Meyer quoted above, and that he describes a very bad figure that we possess of Gampsonyx (he gives a copy pl. 1, fig. 7), while Gampsonyx (Uronectes) is known as completely as we might expect to know a Palæozoic Crustacean.

† *Palæocaris typus*, Coal Measures of Illinois (Proc. Acad. Philad., 1865, p. 49, and Geol. Surv. Ill., ii, 1866, p. 405; iii. 1868, p. 552). *Acanthocaris*, three species from the Coal Measures of Illinois (ibid.). A second species of *Palæocaris* has been described by Woodward from the Coal Measures of England (Geol. Magaz., 1881, p. 533).

‡ Mem. Nat. Acad. Sci., Washington, iii, 1886, and Proc. Boston Soc. N. H., xxiv, 1889.

§ Compare Calman, 1896, p. 801, footnote 1.

This fossil group of Crustaceans has become the more interesting, since very recently a peculiar living species has been discovered in fresh-water pools of the mountains of Tasmania, which was first described by G. M. Thomson* under the generic name of *Anaspides*, and of which W. T. Calman† gives a more detailed investigation, especially with reference to its relation to the fossil forms here under discussion. *Anaspides*, indeed, is the most important discovery among the recent higher Crustaceans, and it is no doubt *a living form belonging to the group Syncarida.* Calman has shown conclusively that the characters of *Anaspides* are a combination of the Podophthalmate type (Thoracostraca) with a completely segmented body and the lack of a carapace, i. e. with Edriophthalmate type (Arthrostraca). But, on the other hand, the details of structure in *Anaspides* point to a closer connection with the "Schizopoda" of the Euphausid-type as well as of the Mysid-type.‡

I think, however, it is best to regard the *Syncarida* of Packard, including the recent genus *Anaspides*, as a group of equal rank with the other chief divisions of the subclass Malacostraca, namely as an *order*, and, indeed, as the most primitive order from which all the others are to be derived: there is no doubt about the genetic relation of the Euphausiacea, Mysidacea, and Decapoda to the Syncarida, but I am convinced that further study will show that also the other orders of Malacostraca, Squillacea, Cumacea, Isopoda, and Amphipoda are to be connected directly or indirectly with this primitive order.

The chief characteristics of the order *Syncarida* (Packard) derived from the morphological features displayed by the recent *Anaspides* would be the following:

*Body with a limited number of distinct segments, differentiated into a "cormus" and a "pleon." No carapace developed. Stalked eyes present. Antennæ with a scale. Cormopods on the coxal joints with "branchial lamellæ," and on the basal joints with an "exopodite." Penultimate segment of the pleon with two well developed appendages forming with the telson a caudal fin.*

Comparing *Crangopsis* with the *Syncarida* we see at once that it is distinguished by the presence of a carapace, thus coming clearly under the subdivision *Thoracostraca.* As we have seen above, we may assign it to a particular order, *Mysidacea*, but we must bear in mind that the typical characters of this order drawn from the appendages of the body are not

* Trans. Linn. Soc. Zool. (2), vol. vi, 1894.
† Trans. Roy. Soc. Edinburgh. vol. xxxviii, part 4, 1896.
‡ Compare Calman, l. c. p. 795 and 801.

recognizable, and therefore its position among the Mysidacea is not beyond doubt. Indeed, I do not believe that *Crangopsis* really belongs to the *order* Mysidacea, but that it is related to the Syncarida. At present, however, we are at a loss to ascertain its true position, since the morphology of the appendages of the body is unknown: yet there is much probability that *Crangopsis* may be a transitional form from the true Syncarida to one of the more specialized groups of Thoracostraca, namely the Mysidacea. Whether we shall connect it systematically with the latter group or with the Syncarida, depends on the knowledge of the other details of structure. In the latter case, the synopsis of the Syncarida ought to be changed as to include this form provided with a carapace.

I may be permitted here to direct attention to a few other Malacostracous Crustaceans found in Palæozoic strata, the position of which with Crangopsis is likely more correct than with the Decapoda.

The oldest form referred to the Decapoda, *Palæopalæmon newberryi*,* from the Upper Devonian of Ohio, has been placed by J. Hall among the "*Carididæ*;" but certainly it does not belong to the typical forms of this group, as the name might suggest, which are now called *Eucyphidea*. Zittel† places this genus among the *Penæidæ*. Although there is no character known which contradicts this position, there is, on the other hand, none which seems to warrant it. On the contrary, no characters are present at all which stamp this fossil as a Decapod: it may belong equally well among the Euphausiacea or Mysidacea. Indeed, in the figure of the only known specimen the carapace appears posteriorly elevated over the abdomen as if separated from the trunk, a feature which suggests a condition similar to that of the Mysidacea or Euphausiacea. But, of course, we cannot judge from this character, as it might be due as well to fossilization.

In the Coal Measures of England a peculiar Crustacean has been found, described by Huxley under the name *Pygocephalus cooperi*.‡ Huxley considers this form to come near to the recent *Mysis*, but to possess some relations to the *Stomatopods*, while Zittel places it among the Decapod-group *Penæidæ*. I should like to endorse the opinion of Huxley in so far as the wanting chelæ, the non-differentiation of maxillipeds and pereiopods, and the presence of exopodites are strongly against its

* Whitfield, this Journal (3), vol. xix, 1880, p. 41, and Ann. N. Y. Acad. Sci., vol. v, 1891, p. 571, pl. 12, figs. 19–21. Hall, Pal. N. Y., vol. vii, 1888, p. 203, pl. 30, figs. 20–23.

† Handbuch d. Palæont., ii, 1885, p. 683.

‡ Quart. Journ. Geol. Soc., London, xiii, 1857, p. 363, pl. 13 and 18, 1862, p. 420.

affinity with the Decapods. *Pygocephalus* may belong to the "Schizopods"* in the old sense, which comprise the Euphausiacea and Mysidacea of recent systems, but we are at a loss to say to which of the two latter orders it may be referred.

In conclusion I may add that no Palæozoic Crustacean is known in which Decapod-characters have been observed.† The only genus *Anthrapalæmon*‡ of the Coal Measures of Scotland and Illinois, which has been referred to the Decapods from the appearance of the external form of the body, has incompletely preserved legs, so that its true position remains doubtful. It may be well to remember that true Decapods, i. e. Crustaceans in which typical Decapod-characters are evident, are not found until the Triassic period, and that it may be possible that they did not exist at all in Palæozoic times. On the other hand, it is sure that upwards from the Upper Devonian period, through the Subcarboniferous, Carboniferous and Permian, Malacostraca have been found, which represent either a mere collective type of this subclass or show even some tendency to become more specialized: at least a differentiation of Thoracostraca and Arthrostraca took place probably in the earliest Subcarboniferous or Upper Devonian period. Remains of this primitive group, which may be conveniently called *Syncarida* (Packard), have not yet been found in Mesozoic or Tertiary strata, *but this group is still represented by the genus Anaspides, living in fresh water on the mountains of Tasmania.*

Princeton University, January, 1897.

* Huxley unites the Schizopods with the Decapods, and, accordingly, he calls *Pygocephalus* a Decapod: but he expressly states its nearer relation to "Mysis," a Schizopod.

† Even an alleged abdomen of a Brachyurous Decapod, *Brachypyge carbonis*, has been described from the Coal Measures of Belgium (Woodward, Geol. Magaz., 1878, p. 433, pl. 11, and de Koninck, Bull. Acad. Roy. Belg. (2), lxv, 1878, p. 83, figs. 1, 2). It is extremely unintelligible why this fossil should belong to a Crustacean at all, and whoever has seen the abdomen of a living crab, cannot doubt that this fossil is no such thing. Probably Brachypyge belongs to the Arachnoidea (compare the Carboniferous Anthracomarti).

‡ Salter, Quart. Journ. Geol. Soc, London, xvii, 1861, p. 529, figs. 1–7. Meek and Worthen, Geol. Surv. Ill., ii, 1866, p. 407, pl. 32, fig. 4, and iii, 1868, p. 554. Etheridge, Quart. Journ. Geol. Soc., London, xxxv, 1879, p. 404, pl. 23.

ART. XXXII.—*On a New Species of the Palinurid-Genus Linuparus found in the Upper Cretaceous of Dakota;* by ARNOLD E. ORTMANN, Ph.D.

THE Geological Museum of Princeton University has lately acquired two unique specimens of a hitherto unknown fossil species belonging to the family Palinuridæ, which are not only the first remains of this group of Decapoda found on the American continent, but which—as regards the completeness of preservation—surpass anything that is known of this group from the European deposits. It is true, Palinuroid-Decapods have been found in Europe, especially in England and Germany, in great numbers, and the systematic relations of these forms—as belonging to the family of Palinuridæ—are beyond any doubt. But there is hardly a form the affinities of which to the living genera of this family have been ascertained: accordingly, for most of them new genera have been created, and although the old generic name of Palinurus has been used for some of these European forms, there is nothing that indicates a closer connection of this *fossil* Palinurus with the *living* Palinurus "sensu strictiore."

The American fossil here to be described not only shows all the chief characteristics of the family, but it is so well preserved that the writer has been enabled to make out its generic position, and he was exceedingly surprised that this fossil from the Upper Cretaceous is congeneric with a species living nowadays in the Japanese seas, namely with *Palinurus trigonus* of de Haan,* the name of which stands at present as *Linuparus trigonus* (d. H.). The genus *Linuparus* created by Gray in 1848 for this Japanese form is—as far as we know—a monotypic genus, containing only that Japanese species just mentioned.

In order to make clear the systematic position of the new fossil, it will be well to give a brief sketch of the generic divisions of the family Palinuridæ, as accepted in modern zoology.†

The family Palinuridæ contains seven recent genera: *Palinurellus*, *Jasus*, *Palinurus*, *Palinustus*, *Linuparus*, *Panulirus* and *Puerulus*. Indeed, some of these genera have not been admitted by some modern carcinologists, but I should say that the differences of these genera are so striking, that one would amply be justified in arranging them into three or

* See de Haan, Fauna Japonica. Crust., decas 5, 1841, p. 157, pl. 39, 40.

† Compare Ortmann, in Zoolog. Jahrb. Syst., vol. vi, 1891, pp. 13–38. I should mention here, that some of the generic names used by me in this revision do not comply with the rules of nomenclature accepted generally. Thus *Avus* should be *Linuparus*, *Senex* should be *Panulirus*, and *Puer* ought to be changed, since it has been preoccupied. (I should like to propose *Puerulus* for it.)

four different families. Only Palinurus and Palinustus on the one hand, and on the other Panulirus and Puerulus are more closely related to each other: the other genera differ so widely that they indicate as many lines of development within this family, which are separated since very old geological times. It may be possible to trace back the separation of these lines of development into the earlier Jurassic or even into the Triassic period.

There are three chief groups, namely: 1, that of *Palinurellus* and *Jasus;* 2, that of *Palinurus*, *Palinustus* and *Linuparus;* 3, that of *Panulirus* and *Puerulus.*

According to the morphological characters the first may be called the more primitive, the second the typical, the third the more advanced group. But perhaps it would be well to place *Palinurellus* and *Jasus* in separate groups, since both—although agreeing in some characters not found in the other genera—are so widely different, that no closer genetic relation seems to be present.

The most striking character of *Palinuridæ* is the connection of the frontal parts of the carapace with the so-called segment of the antennulæ as well as with the epistoma, and, on the other hand, the fusion of the basal points of the stalk of the antennæ with the epistoma. The frontal part of the carapace is always united with the segment of the antennulæ outside of the eyes, on either side, but in the two genera first named there is a median connection besides: the rostrum is bent downward and covers completely or partially the bases of the eyes, thus reaching and joining the segment of the antennulæ. These two genera—Palinurellus and Jasus—are further characterized by the lack of a stridulating apparatus, formed by the first free joints of the antennæ rubbing against the segment of the antennulæ, which seems to be present in all the other genera.

The second and third groups are more closely related to each other, but they are distinguished by one important character: in the second the epistoma is divided longitudinally by a deep furrow, which no doubt indicates the former separation of the basal joints of the antennæ fused into the epistoma. This furrow is wholly wanting in the third group, the epistoma being smooth and even medially. The disappearance of this indication of the primitive separation of the basal joints of the antennæ stamps the third group as a more advanced one than the second. Besides, there is another difference: in the second group the flagella of the antennulæ are always short, while in the third group they are very much longer.

Examining our fossil form, we see at once that it belongs to the second group. The larger specimen shows plainly the connection of the carapace with the epistoma and with the segment of the antennulæ, outside of the bases of the eyes, while

no median connection is present. The epistoma shows the median longitudinal groove characteristic of the second group. The flagella of the antennulæ, however, are not preserved.

There are three genera in the second group. The first is the type genus of the family, *Palinurus* (containing two living species); the others are *Palinustus* and *Linuparus* (containing only one species each). *Palinustus* was proposed by A. Milne-Edwards* for a deep-sea form from the West Indies. The description of it is very poor and even incorrect in some respects, and no figure of it has been published. I am, however, enabled—through the kindness of Professor Alexander Agassiz, who lent me the type specimen for examination—to state, that Palinustus comes very near to Palinurus, and differs only in the weaker "frontal horns," which are placed on the outer edge of two very peculiar plates projecting horizontally from the frontal margin and truncated squarely at the apex. In Palinurus these projecting frontal plates are wanting and the "frontal horns" are formed by two large, compressed, nearly falciform spines placed close to the frontal margin on either side of the rostrum. In all other respects Palinurus differs only slightly from Palinustus. The differences of both genera from *Linuparus* are the following. In *Palinurus* and *Palinustus* the carapace, especially the part behind the cervical groove, is evenly arched from side to side, i. e. of sub-cylindrical shape, and it is covered by a multitude of spines and spiny tubercles, becoming scaly in the hinder part. The frontal horns are compressed and separated by a wide space. In *Linuparus* the hinder part of the carapace is distinctly carinate, three keels being present, a median one and two lateral ones. The surface is covered with granules, and a few small spines placed chiefly on the anterior part, thus differing strikingly from the spiny appearance of the carapace of the first two genera, and, further, the frontal horns of the living Linuparus lie close together and are depressed (not compressed), forming two broadly triangular plates projecting from the middle of the frontal margin.

Our fossil form comes very near to *Linuparus* in the shape and armature of the carapace. There are three distinct longitudinal keels on the hinder part of the carapace, and only a few short spines distributed in a similar manner as in the living Japanese form. But there is a difference in the frontal horns. The latter are compressed, as in Palinurus, but nearer to the median line. The horns are smaller than in Palinurus and a little inclined, diverging from the bases outward, and thus they are exactly intermediate in shape and position between the living Palinurus and the living Linuparus: the distinct lateral compression comes near to that of the former genus, but the inclining direction looks like an incipient depression, and in

* Bull. Mus. Compar. Zool., vol. viii, 1880, p. 66.

their closer position to the median line, the horns approach also the condition seen in Linuparus.*

There is no doubt that we are to place the fossil form in the genus Linuparus, and although the frontal horns form in some degree a connection with Palinurus, there are a couple of other characters of minor importance exhibited by our fossil which occur only in the Japanese *Linuparus trigonus*, as will be pointed out in the following detailed description of the new fossil, which I propose to name

*Linuparus atavus*, spec. nov.

The two specimens of the Princeton Museum, both males, were collected by Mr. H. F. Wells in the Niobrara group (Upper Cretaceous) at the head of Cotton-Wood Creek, Mead Co., South Dakota. They were broken into numerous pieces, but have been put together again very skilfully by Mr. Gidley. The matrix being extremely hard, it was deemed dangerous to try to work out some parts of the body more completely; thus some parts in either specimen are still imbedded in the matrix: but luckily the specimens supplement each other in an admirable manner, so as to leave only a few details of minor importance unknown. See figures 1–4, p. 297.

MEASUREMENTS.

*Of larger specimen (a).*

| | |
|---|---|
| From anterior frontal margin to hinder lateral corner of carapace | 79mm |
| Length of 4 posterior abdominal segments + telson (hinder part of the latter imbedded in the matrix) | 77 |
| Length of the three free basal joints of the antennæ (outer margin) | 39 |
| Breadth of frontal margin | 38 |
| Distance between the frontal horns, | 8 |
| Breadth of carapace, posterior end | 36 |

*Of smaller specimen (b).*

| | |
|---|---|
| Length of carapace | 60mm |
| Length of 4 anterior abdominal segments | 31 |

Allowing, in the larger specimen, for the first two abdominal segments one and a half of the length of the third segment (14mm), the approximate total length of the body would be 177mm.

* This intermediate shape of the frontal horns settles the question whether the triangular frontal processes of Linuparus are a bilobed rostrum (as de Haan believes) or the homologues of the frontal horns found in other genera of Palinuridæ. *They are frontal horns.*

Specimen (*a*) shows beautifully the frontal margin, the segment of the antennulæ, the stalks of the antennæ and parts of the flagella, the basal joints of the antennulæ, the epistoma, and the hinder part of the abdomen. The upper surface of the carapace is much crushed, and the place of the sternum is occupied by a large hole. Of the abdomen, the four last abdominal segments and the telson are present; of the first and second segments only a few pieces are recognizable. In specimen (*b*) the upper surface of the carapace is nearly complete, there is only a hole occupying the gastrical region and a few smaller ones; the frontal horns are better than in the first specimen. The anterior part of the abdomen and the sternum are complete in specimen (*b*), but the anterior part of the body (beyond the frontal margin) is imbedded in the matrix, and the posterior part of the abdomen is wholly absent. Parts of the maxillipeds, pereiopods, and pleopods are visible in both specimens.

*Description.* — *Carapace* nearly rectangular in outline. Frontal margin truncate, nearly straight, connected with the segment of the antennulæ on both sides of the eyes. Frontal horns approaching each other, compressed, but diverging from the bases outward, their anterior margin with a few small teeth, no median rostral spine being visible. Antero-lateral angles formed by spines. Cervical groove distinct. Anterior part of carapace (in front of the cervical groove) with two spines just behind the frontal horns, which are a little more distant from each other than the latter, and with three tubercles forming a triangle. A curved, longitudinal series of three spines between the median line and the lateral margins. Hinder part of carapace tricarinate, each keel bearing a number of small spines. Otherwise the surface of the carapace is only granulate and punctate. (The arrangement of the spines on the anterior part is very like to that of the living Linuparus!)

*Abdominal segments* in the median line provided with short, conical spines. (Similar spines are found in *Linuparus trigonus* on the anterior segments, but are wholly wanting in all other genera of Palinuridæ, except in one species of Puerulus: here, however, they are of a different character!) The first segment has only one spine, the second has two simple spines, on the third segment the posterior one is provided, in specimen (*a*) with one, in specimen (*b*) with two additional tubercles, one behind the other. The fourth segment has two double-spined tubercles; the tips of the spines are placed one behind the other. The fifth segment has two simple spiniform tubercles. On the sixth segment, however, are two low double spines, placed side by side each near the median line, and on the posterior margin are two small spines placed close to the median line. The segments from the second to the fifth have each two sharp tubercles on each lateral part; the sixth has only one. The epimera are spined on the margins, but the

exact number of the spines cannot be determined. Each abdominal segment has a transverse furrow passing across the back between the anterior and the posterior median spines; these furrows are very distinct on the second, third and fourth segments, while they are obsolete on the first, fifth and sixth. Of the telson only a small part of the anterior portion is exposed; the posterior end, which was probably—as usual in this family—soft, is imbedded in the hard matrix.

*The segment of the antennulæ* is very like that of Palinurus or Linuparus. It is narrow, elongate-triangular; the lateral borders form a blunt, elevated ridge. The *epistoma* has a deep median longitudinal furrow, which is bordered anteriorly by a strongly elevated, oblong tubercle on both sides. The phymacerite (opening of the green gland) is visible only on the left side of specimen (*a*). The *sternum*, exposed beautifully in specimen (*b*), is elongate-triangular in outline. The lateral borders have three spiniform tubercles near the insertions of the second, third and fourth pereiopods, and a similar median tubercle a little in advance of the level of insertion of the fifth pereiopods.

Of the *antennulæ* only parts of the basal joint are preserved. The *antennæ* show the stout and enlarged form usual in the family. The stems have three free joints, the basal one being greatly enlarged and dilated on the inner margin, thus forming, with the segment of the antennulæ, that peculiar "stridulating apparatus" found in the genera of group 2 and 3 of the family. The two other basal joints of the antennæ are narrower than the basal one, but still large and powerful. All three joints are furnished with a number of smaller and larger spines. Of the *flagella* only a couple of fragments are preserved, but these show a very peculiar feature only found, among the living genera, in Linuparus: there exists dorsally and ventrally a distinct longitudinal furrow, so as to render the cross section oval with a constriction in the middle.

Of the *mouth parts*, traces of the strong and powerful *mandibles* are seen in specimen (*a*), of the second maxillipeds in specimen (*b*), and of the third maxillipeds in both. Of the latter the distal joints, carpus, propodus, and dactylus, are broken away. The interior margin of ischium and merus is spiny. No traces of an exopodite have been discovered, but it is probable that it is broken away or still imbedded in the matrix.

Of the *pereiopods* (thoracic legs) the first seems to be the stoutest, the second the longest. In specimen (*b*) all the joints of the latter are preserved on the right side (but partly covered by the matrix). The dactylus reaches as far as the end of the stalks of the antennæ, and it is long and slender. The dactylus of the first periopods is nowhere visible, but in both specimens the propodus of the left sides, showing plainly that

no chelæ were developed, as required by the diagnosis of the family. The following pairs of pereiopods decrease in size and thickness. The fifth pair shows plainly in both specimens the male sexual opening. The distal parts from the merus onward are not present in the fifth pair.

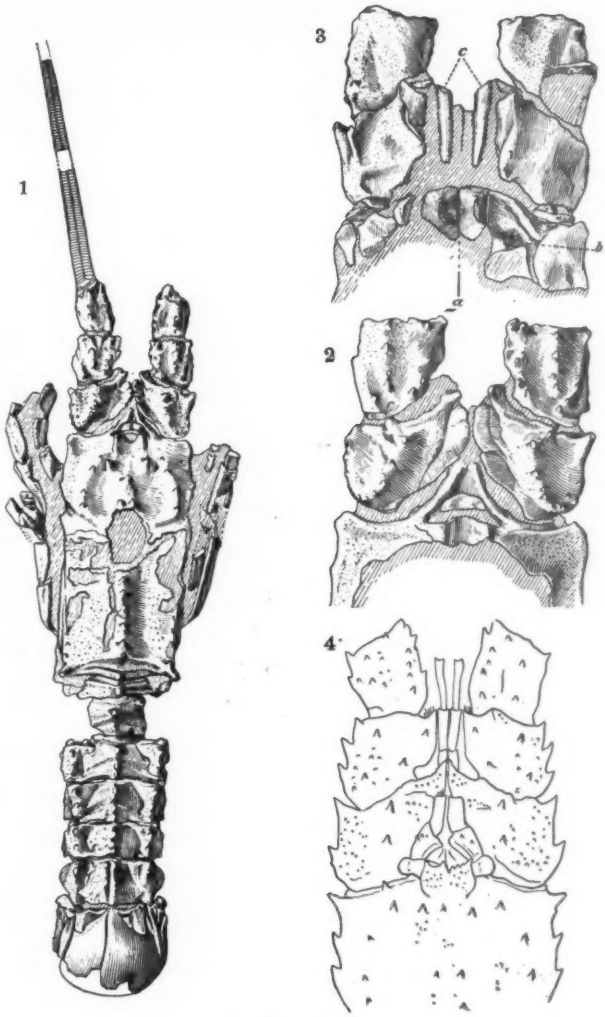
Traces of abdominal appendages (*pleopods*) are discernable in both specimens; the right one of the fourth segment in specimen (*a*) is the best preserved, consisting of an oval plate, which is finely striated. Sexual appendages are wanting.

Thus we see that the position of this fossil form with the genus *Linuparus* is warranted not only by the tricarinate carapace, but also by other characters of minor importance, such as the distribution of spines on the carapace, the armature of the abdomen (which in its general plan is exactly like that of *Linuparus trigonus*, and differs from Palinurus as well as from the other genera of the family), and the peculiar shape of the flagella of the antennæ. Only the frontal horns differ from those of the living species, but, as I have shown above, they are intermediate between that species and the condition seen in Palinurus, and this difference should be regarded as of only specific value: I do not think the shape of the frontal horns justifies the creation of a new genus, and this would be the only way left, if we do not wish to unite this fossil generically with the living Japanese species.

Altogether, there is no doubt that the fossil described above is the nearest relation of the living *Linuparus trigonus*, none of the other living species coming so near to that Japanese Crustacean. This fact is extremely interesting, since it proves that the genus Linuparus only slightly modified existed as far back as the Upper Cretaceous time, and, indeed, one might be induced to regard *Linuparus atavus* as the direct ancestor of the living species.

In conclusion, this new fossil gives a hint as to the origin of the geographical range of the genus Linuparus. Linuparus is not—as might be supposed from its present exclusive distribution in the Japanese seas—a form indigenous to that part of the world: the Japanese seas are not the "center of origin" of this genus, but the living species is to be regarded as the only "relict" left from a former wider distribution. Probably this genus (like most of the other Mesozoic marine animals) possessed formerly a more or less cosmopolitan distribution, but it has been restricted gradually, and the only remnant left at the present time is the Japanese *Linuparus trigonus*, which is to be regarded, accordingly, as a very ancient type among the living Decapods.

Princeton University, February, 1897.




EXPLANATION OF FIGURES.

*Linuparus atavus.*

FIGURE 1.—Upper view of larger specimen. ½ nat. size. (Some details of structure of the carapace are supplemented from the smaller specimen.)

FIGURE 2.—Frontal parts of carapace and base of antennæ, viewed from above, and showing stridulating apparatus. Nat. size (large specimen).

FIGURE 3.—do., viewed from below. Nat. size.—*a*. Longitudinal groove, dividing the epistoma; *b*. Phymacerite; *c*. Basal joints of antennulæ.

FIGURE 4.—*Linuparus trigonus* (dH.), living Japanese form, the same parts as in fig. 3, copied from the "Fauna Japonica" for comparison. ½ nat. size.

ART. XXXIII.—*Studies in the Cyperaceæ;* by THEO. HOLM.

VI. *Dichromena leucocephala* Vahl, and *D. latifolia* Baldw.

THE genus *Dichromena* was established by Michaux (l. c. xiii) upon the plant which he named *D. leucocephala*, on account of the snow-white inflorescence, while the generic name, derived from δίς and χρῶμα, should merely refer to the partly discolored involucre. No other name could be more suitable for this singular species, but our plant has, nevertheless, met with the same fate as so many of the other North American plants, viz: to get its name changed and to become confounded with totally different species. Professor N. L. Britton, for instance, changed its name to *Dichromena cephalotes*, while Professor A. S. Hitchcock (l. c. ii) suggested the name *D. colorata*, since he thought that Linnæus had this plant before him when he described his *Schœnus coloratus* (l. c. vii). It is not, however, likely that this last change of name will hold good either, for two reasons: first, that Linnæus would hardly have called our discolored *Dichromena* "colored;" and second, because the Linnean diagnosis does not prove that these two plants are really the same.

In regard to the specific name "coloratus," Linnæus did not use this term for discolored organs, but he used "*variegatus*," for instance (l. c. v) "Arundo indica variegata," "Gramen paniculatum aqu. phalaridis sem. folio variegato," and "Agrifolium foliis ex albo variegatis," which plants exhibit the same discoloration as our *Dichromena*. Furthermore, in his Philosophia botanica (l. c. ix) Linnæus employed the terms "albicans" and "pallescens" for such organs as are whitish or pale green, viz: "Abrotanum cauliculis albicantibus," etc., besides that he named a species of *Schœnus* "*niveus*" (l. c. x) in contrast to his *Schœnus* "*coloratus*"! These two species are now generally recognized as *Kyllinga triceps* and *K. monocephala*, of which the first one is described by Kunth (l. c. iv) with "squamis hyalino-albidis" (*niveus*), while the other species, *K. monocephala*, has the same organs "purpureo-punctulatis" (*coloratus*).

There are, furthermore, if we examine the diagnosis of *Schœnus coloratus*, some points which seem to show that Linnæus did not intend to describe our *Dichromena;* he says, as follows: "*Schœnus* coloratus, culmo triquetro, capitulo subrotundo, involucro longissimo planò variegato." This last character may suit very well for a *Dichromena*, although the involucre of some species of *Kyllinga* is known, also, to show a

similar discoloration. But the very long involucre ("involucro longissimo") does not fit as well for a *Dichromena* as for a *Kyllinga*, and our *K. monocephala* has, as we remember, the involucral leaves very long, much longer than in any species of *Dichromena*. The character "capitulo subrotundo" is, also, without doubt meant for the *Kyllinga*, since Linnæus would surely not have overlooked the several spikes in *Dichromena* with the flowers and bracts almost "biseriate." We really feel assured that if Linnæus had seen our *Dichromena*, he would rather have referred it to *Cyperus*, on account of its biseriate bracts, etc. It is, furthermore, difficult to detect any organ in *Dichromena* which Linnæus observed to be so conspicuous in order to name the species "*coloratus*." The inflorescence of *Dichromena leucocephala* is, as its name indicates, snow-white, while that of *Kyllinga* is purplish-dotted.

The later editors of Linnæus' works, for instance Murray (l. c. xii), refer *Schœnus coloratus* and *S. niveus* respectively to *K. monocephala* and *K. triceps*, and Giseke (l. c. x), in accordance with Rottbœll (l. c. xiv), makes the following statement: "*Kyllinga* Rottbœlli adeo similis est *Schœno*, ut duæ ejus species a Linnæo patre sub illo comprehensæ fuerint, nomine 'colorati et nivei' quæ jam *Kyllinga monocephala* et *triceps* vocantur." Finally, Willdenow (l. c. xi) reached to the same conclusion as Giseke and Rottbœll, and it must be noted that this author, Willdenow, states that he had seen specimens of *Kyllinga monocephala*, a fact that perhaps will be sufficient to decide the identity of the *Schœnus* with the *Kyllinga*, instead of with our *Dichromena*.

In considering now our plants, they are of a very singular aspect with their partly discolored involucre and white spikes, but an examination of the details will soon show that our plants are not different in any essential particular from most of the other genera of the *Scirpeæ*. The genus *Dichromena*, for instance, has three characters in common with *Cyperus*, viz: the almost biseriately arranged bracts and flowers, the lack of bristles, and finally the development of one of the internodes of the stem into a long scape with the bracts and inflorescences crowded at the apex. But it is at the same time readily distinguished from *Cyperus* by the achene, which in *Dichromena* is crowned with the persistent base of the style.

Let us pass to examine the internal structure of our plants, beginning with the species *leucocephala*. This species shows the general features, which are known to be characteristic of the *Cyperaceæ*, besides that there are a few points in which it seems to differ from all the others which, so far, have been examined. The stem-leaf has a long flat blade, which is perfectly smooth like the other parts of the plant, and green

in contrast to the partly discolored involucral leaves. The epidermis of the upper face consists of very large cells, which cover the entire surface, excepting near the margins, where a relatively large group of stereome is located, above which the epidermis-cells have become very small. The upper face of the blade is thus covered with bulliform-cells, in which respect our plant reminds us somewhat of *Cyperus fuscus*, which has been described and figured by Duval-Jouve (l. c. i). The cells of the epidermis of the lower surface are much smaller, and their walls are slightly undulate; we find, also, here the internal cones, which seem to be constantly developed in the epidermis, which covers the stereome. Stomata are to be observed on this, the lower surface; they are not very prominent, and they form longitudinal bands underneath the mesophyll. This last tissue occupies a very large part of the blade and consists of rather closely packed palisade-cells on the lower surface, while it shows a more open tissue on the upper face, just underneath the bulliform-cells. We notice, therefore, that the palisade-tissue and the stomata are exclusively restricted to the lower face of the leaf-blade, a fact which seems due to the extraordinary development of the upper epidermis. The palisade-cells are mostly arranged vertically upon the leaf-surface, but we have, also, observed an approximately radial arrangement around the mestome-bundles. The cells of the mesophyll near the upper surface are polyhedric and leave room for numerous, but small, intercellular spaces. While only a few cells of the lower epidermis contained tannin, the mesophyll was observed to possess quite a number of such reservoirs. Very distinct and well differentiated from the mesophyll is the colorless parenchyma-sheath, which borders on the mestome-bundles and partly surrounds these. We have seen from previous studies that this parenchyma-sheath is generally interrupted by the stereome in the large mestome-bundles, while it forms a closed ring around the smallest ones, which as a rule are not in contact with the hypodermal groups of stereome. *Dichromena* forms, however, an exception to this rule, since, as we shall see later, the colorless parenchyma-sheath does not surround even the smallest mestome-bundles, but is, also, here interrupted by small stereome-elements, widely separated from the epidermis of both faces of the leaf-blade. Inside the colorless parenchyma-sheath is the usual mestome-sheath, which is here

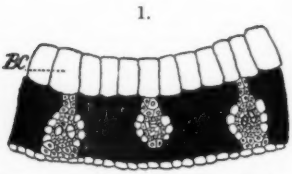



FIG. 1. Transverse section of the leaf of *D. leucocephala*. *B. C.* the bulliform-cells. 75 × natural size.

composed of equally thickened cells, those on the leptome-side being smaller and with narrower lumen than the others. The mestome-bundles seem to represent three different forms in the leaf of *Dichromena*, but not so much in regard to the development of the leptome and the hadrome as in regard to the difference in their mechanical support. The largest bundles have the leptome and hadrome well developed and not separated from each other by thick-walled mestome-parenchyma; these bundles are supported by large groups of stereome on both faces, both groups extending from the corresponding epidermis. The mestome-bundles, which may be designated as those of second degree, have, also, a well differentiated leptome and hadrome, besides two groups of stereome, but this tissue does not here extend to the epidermis of the lower face. The smallest bundles contain mostly leptome, and their mechanical support consists only of a few stereome-cells on both faces of the bundle, thus interrupting the parenchyma-sheath, but without coming in contact with the epidermis. The general distribution of the stereome has, thus, already been indicated, and it may be added that no isolated groups of this tissue were observed in the leaf of our plant, not even in the margin, where, although present, the stereome was in connection with a small mestome-bundle. The leaf of *Dichromena* shows, therefore, a rather firm structure in regard to the dense mass of mesophyll, which is entirely destitute of any openings large enough to be designated as lacunes. It has, also, been stated that tannin was observed in the epidermis, and quite abundantly in the mesophyll, besides that it was, also, traced in the hadrome of most of the mestome-bundles.

2.

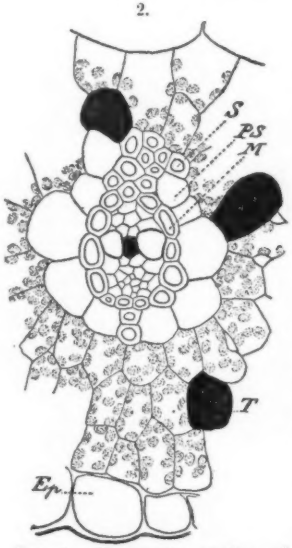



FIG. 2. Transverse section of a mestome-bundle from the leaf-blade. *Ep*, the lower epidermis; *S*, stereome; *PS*, parenchyma-sheath; *M*, mestome-sheath; *T*, tannin reservoir, indicated with black in four cells of the section. 400 × natural size.

If we now examine the leaves of the involucre, we find a very singular structure, corresponding to that which Lagerheim (l. c. iv) has observed in *D. ciliata* Vahl from Ecuador. The discolored part, the base of the involucre, has the epidermis of the upper face developed as a stratum of large papillose

cells, while the lower epidermis consists of somewhat smaller cells. The mesophyll is in this part of the involucre composed of rather long, loosely connected cells, all destitute of chlorophyll, giving the leaf the peculiar white aspect in contrast to the upper part, in which the mesophyll is of usual structure and well provided with chlorophyll. The mestome-bundles are small, but represent, nevertheless, the same forms as we have described as characteristic of the proper leaves; cells containing tannin were observed in the mesophyll and in the hadrome. Stomata were observed, but confined to the lower surface of the green part of the involucre.

As to the aerial stem: this is perfectly smooth, terete, slightly furrowed and hollow. It contains a bark rich in chlorophyll and composed of about eight layers of very regularly arranged palisade-cells, which are closely packed, except underneath the stomata, which are well represented in the epidermis. The palisade-tissue does not form closed rings in the

3.

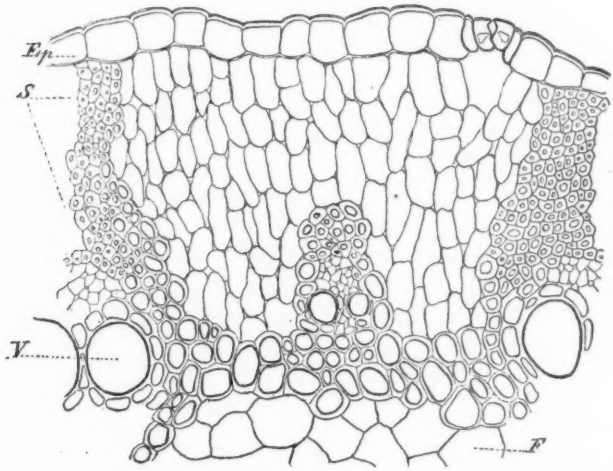



FIG. 3. Transverse section of the stem of *D. leucocephala*. *Ep*, Epidermis; *S*, Stereome; *V*, vessels; *F*, fundamental tissue. 320 × natural size.

stem, but is interrupted by the stereome which support the mestome-bundles. There are three concentric bands of mestome-bundles in the stem, and they are very regularly arranged and represent three degrees of development. Those of the outer- and inner-most band show exactly the same development in regard to the mestome; the leptome and hadrome are very

highly developed, but there is a difference in regard to their mechanical support. Those of the outer band have a large group of stereome all around the bundle, and especially on the leptome side from where the stereome extends outwards to the epidermis. The mestome-bundles of the innermost band are but a few in number and their mechanical support is very insignificant, there being only a few stereomatic cells on the leptome- and the hadrome-side of these bundles. The third form of mestome-bundles are in regular alternation with those of the outer band; they are very small, round and are merely supported by a small group of mechanical tissue on the leptome-side, which group is widely separated from the epidermis by the bark-parenchyma. The leptome and hadrome are, however, well differentiated in these small bundles. (Compare figure 3.)

In considering now the stereome, this forms, as already stated, groups of various strength for the support of the mestome-bundles, and it forms besides an uninterrupted ring inside the two outer bands of mestome-bundles, thus encircling those of the inner band. The innermost part of the stem is occupied by a fundamental tissue, which is composed of large, thin-walled cells, bordering on the rather wide central cavity. Tannin-reservoirs were only observed very scarce in the stem, and they seemed to be confined to the bark, besides that one cell of the hadrome between the two large vessels in all the mestome-bundles was observed to contain this matter.

The rhizome of our species is well developed, creeping and of a comparatively firm structure. It contains a huge bark-parenchyma of roundish cells, which forms a circle all around the central-cylinder. Very conspicuous are the numerous tannin-reservoirs, which abound in the bark, increasing in size towards the epidermis. While no typical endodermis is differentiated, there is, however, a closed ring of stereomatic tissue, just inside the bark, but the cells of this stereome are rather open and with thin walls. It surrounds the entire system of mestome-bundles irregularly scattered in the fundamental tissue, and it is, also, represented as supporting groups on both faces of the mestome-bundles, especially on the innermost face of these. There are two distinct forms of mestome-bundles observable, viz: the ordinary collateral and the so-called concentric, the last of which occur here as perihadromatic; these two forms do not, however, show any special arrangement, but are to be observed scattered among each other. We stated above, that tannin-reservoirs were abundant in the bark; they are again to be observed in the fundamental tissue, where they are quite numerous, besides in the stereome and the

hadrome of nearly all the mestome-bundles. The rhizome shows thus a dense and solid structure with no trace of lacunes or even ducts, the cells of the bark-parenchyma leaving only very narrow intercellular-spaces.

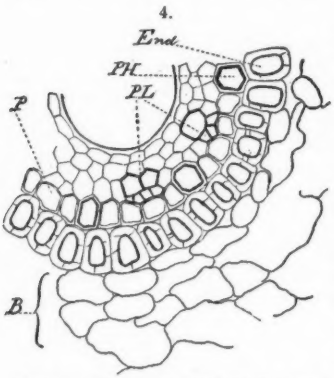



FIG. 4. Transverse section of a root. *B*, the bark-parenchyma. *End*, Endodermis: *P*, Pericambium; *PL*, Protoleptome; *PH*, Protohadrome. 400× natural size.

The root shows a very simple structure, which agrees in all respects with that of the *Cyperaceæ* in general. The epidermis becomes thrown off by age, but is then substituted by a thick-walled hypoderm, which surrounds the very open bark-parenchyma, showing numerous lacunes, which have arisen by the tangential collapsing of the bark-cells. The innermost bark is differentiated as a very thick-walled and porous endodermis (*End* in figure 4) which surrounds the pericambium; this last is as usual in the *Cyperaceæ* (with the only exception of *Carex Fraseri*, so far as is known) interrupted by elements of protohadrome, which therefore lie close up towards the endodermis. In alternation with the protohadrome are to be observed small groups of protoleptome, while the center of the root is occupied by a huge vessel, surrounded by a few layers of conjunctive tissue.

This is the general structure of *Dichromena leucocephala*, and if we now institute a comparison of these structures with the corresponding organs of *D. latifolia*, we may be somewhat surprised to find exact uniformity rather than any differences. Both plants have long been unanimously recognized as distinct species, although the differentiation seems to have been based on so slight a character as "the tubercle of the achene being decurrent down the margins." This character did not, however, seem sufficient to Kunth for separating them as two species, and he therefore did not accept the species *latifolia* without a certain reservation and doubt: "*Dichromenæ leucocephalæ* affinis, sed major. Mihi adhuc dubia."

A comparison of their structural characters may simply be expressed in this way, that the mechanical tissue is somewhat more strongly developed in *D. latifolia*, but otherwise no difference was to be detected. That this uniformity in anatomical structure, as observed in the most important organs of the

plants, should be considered sufficient to unite these supposed species is more than probable. There seems always, even in closely related species, to be at least a few distinct anatomical characters to be observed, which in connection with similar morphological ones may prove the species to be valid; but we have, so far, been unable to trace any such divergences as warrant the separation of *Dichromena latifolia* Baldw. from *D. leucocephala* Vahl.

Washington, D. C., February, 1897.

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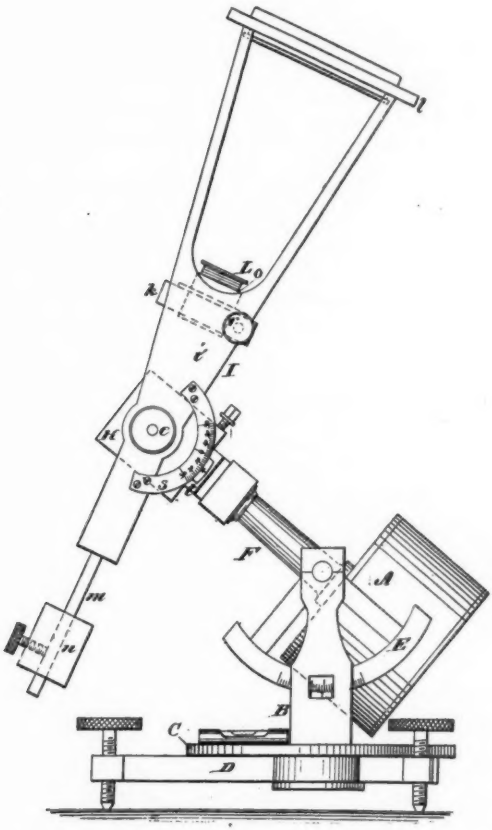
XIV. Rottbœll, Chr. Fr.: Descriptiones et Icones plantarum. Kjœbenhavn, 1786, p. 12.
XV. Schwendener, S.: Das mechanische Princip im anatomischen Bau der Monocotylen. Leipzig, 1874, p. 82.

ART. XXXIV.—*On an Improved Heliostat invented by Alfred M. Mayer;* by ALFRED GOLDSBOROUGH MAYER.

IN 1885 my father, the late Professor A. M. Mayer, invented a heliostat which is superior in many respects to all forms of this instrument at present existing. As far as I am aware, my father never described his invention, and believing that an

1.

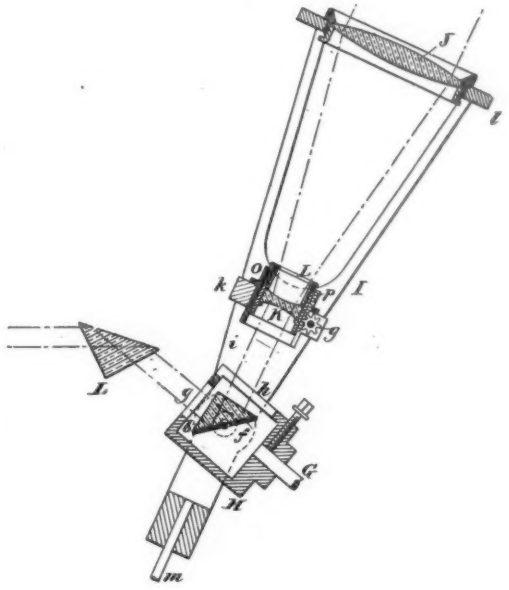



account of its construction may be of service to science, I herewith present a description of the instrument.

The common forms of heliostats consist of one or more plane mirrors carried by a driving clock so as to maintain a solar beam continuously in one direction. The plane mirrors have to be of considerable size, and for accurate work are costly, moreover it is a matter of much difficulty to insure a constant direction of the reflected light owing to the complexity of the mechanism of the driving apparatus.

The heliostat here described avoids these difficulties, is of very simple and cheap construction and possesses the unique advantage that it will maintain a parallel, convergent, or divergent solar beam in one direction with perfect steadiness, and will produce a highly illuminated field of uniform intensity with an amount of heat much less than that given by the forms of heliostats hitherto used.

2.




The essential and characteristic parts of the instrument (fig. 2) consist in a biconvex lens (J) which receives the sun's light and produces a convergent beam that is rendered parallel by the small biconcave lens (K). The beam is then reflected in some desired direction by means of the totally reflecting prism (*f*). The two lenses, J and K, and the prism, *f*, are all

arranged upon a common axis, and mounted equatorially in a suitable frame-work adjustable to the sun's declination by means of the graduated arc (S, fig. 1). This frame work is controlled by a driving clock (A, fig. 1) of the type commonly used in other heliostats. The beam of light which is reflected from the prism ($f$) may be thrown in any direction by means of the reflecting prism, L (fig. 2), which is placed somewhere near but forms no essential part of the instrument.

This heliostat is especially well adapted to microscopic and spectroscopic work and to projection with the lantern. By its means a very intense beam of sunlight may be obtained, which is so remarkably free from heat that it may be passed with perfect safety through microscopic slides containing the most delicate objects. In this manner beautifully well-defined images of microscopic objects were thrown upon a screen under a magnification of 3800 diameters.

Harvard University, August 1st, 1897.

## Art. XXXV.—*Pseudomorphs from Northern New York;* by C. H. Smyth, Jr.

### *Pyroxene after Wollastonite.*

While studying the mineral deposits of contact origin in the town of Diana, Lewis County, the writer collected several specimens which presented the appearance of pseudomorphs; and such, upon further examination, they have proved to be.

The surfaces of these specimens are rough and rounded, as is so commonly the case with pseudomorphs, while fractures show the crystals to lack homogeneity of structure, the mineral of which they consist having a pronounced cleavage, which has different directions in different parts of the crystal. The specimens are pale greenish-gray, becoming colorless in thin splinters and in sections. While the rough and curved faces and rounded edges make it impossible to determine the original form with absolute accuracy, the approximate measurements afforded, together with the habit of the individuals and of the aggregates, can hardly be explained except as inherited from wollastonite, an abundant mineral of this locality.

Thin sections show each crystal to be made up of a number of individuals of monoclinic pyroxene, in irregularly bounded plates, variously oriented with reference to each other and to the external form derived from wollastonite. The pyroxene shows the usual optical and pyrognostic characters, is colorless, and free from inclusions other than calcite, which occurs as rounded or sinuous patches in and between the plates of pyroxene. This calcite seems to be an infiltration from the surrounding limestone, rather than a product of the alteration of the original wollastonite, though part may be of the latter origin.

In the hope of obtaining further evidence as to the nature of the mineral replaced by pyroxene, a number of specimens of Diana wollastonite have been examined, and, in several of them, grains and strings of pyroxene have been found. While these grains look rather like inclusions, it seems quite certain that in reality they mark the initial stages of the process which finds its completion in the specimens above described. This is even more strongly indicated by thin sections in which the pyroxene may be seen filling cleavage cracks and irregular fissures and cavities in the wollastonite.

The chemical changes involved in the alteration of wollastonite into pyroxene are much simpler than in the case of scapolite and mica, described below. Yet, nevertheless, the former alteration seems to be much less common. This is not surpris-

ing, however, as wollastonite is a metasilicate of simple constitution, while scapolite belongs to the less stable class of orthosilicates and has a very complex molecular structure.

The change of wollastonite into pyroxene is an illustration of the rule, referred to below, that, throughout this region, the addition of magnesia is very common in the formation of pseudomorphs.

### *Mica after Scapolite and Pyroxene.*

Several years ago the writer described* briefly a variety of crystalline limestone, characterized by the presence of abundant crystals of scapolite, which occurs near Gouverneur, N. Y. Since that time the rock has been quarried to some extent for road metal and a supply of material favorable for study has been afforded. The exposure is beside the highway leading from Gouverneur to Hailesboro, and about half a mile south of the former village.

The scapolite is rather uniformly disseminated through the limestone over an irregular area of several acres, projecting above weathered surfaces, and appearing as dark patches on fresh fractures. With it are associated a light-gray pyroxene, brown amphibole, titanite, a little pyrite, and an abundance of rich brown mica. While this association of species is suggestive of contact metamorphism, the irregular diffusion of the minerals over a considerable area, together with the absence of all zonal structure and of any exposure of igneous rocks, necessitates the correlation of the minerals with the general metamorphism of the region, by whatever cause or causes that may have been produced.

None of the minerals show perfect crystal form, but the scapolite and pyroxene, with which the present communication is particularly concerned, are often distinctly prismatic and sometimes bounded by fairly good planes in the prism zone. The crystals range in size from very small up to a maximum length of about three inches. The color of the scapolite is a dull grayish-black and in most cases it appears to be, at least slightly, decomposed and softened. Some specimens are, however, quite tough and lustrous. Close to many of the crystals the enclosing limestone shows a greenish or yellowish zone which looks almost like serpentine.

The interesting feature of the scapolite is the relation it bears to the associated mica. The latter mineral occurs in prismatic forms which, at first glance, might be taken for simple crystals of phlogopite. But, on closer examination, it is seen that each prism is a complex aggregate of mica plates, the per-

* Trans. N. Y. Acad. of Sciences, xii, p. 213.

fect basal cleavage having the greatest variety of orientation in different parts of the crystal. The obvious conclusion, that the mica is pseudomorphous, is entirely substantiated by occasional specimens of unusual perfection showing the crystals composed wholly of mica, but having eight, instead of six, faces in the prism zone, and thus reproducing the form and habit of the scapolite.

The intermediate stages in the production of the pseudomorphs of mica after scapolite are abundantly shown. Indeed, most of the scapolite crystals are partially changed. As a rule, the alteration proceeds from the margin towards the center, but there are many exceptions, and the operation shows much irregularity.

In thin sections, the scapolite shows a strong double refraction and the species is probably near wernerite. Very abundant black inclusions, probably carbonaceous, account for the black color of the mineral. These inclusions often show a perfect zonal arrangement, and there is nearly always a surface layer which is quite free from them. In the growth of the pseudomorphs this regularity of distribution becomes obscured, and there seems to be a tendency for the inclusions to become somewhat segregated. As alteration proceeds, the double refraction becomes very weak, the mineral takes on a rather fibrous structure and the fibers have a positive optical character. In this condition the mineral behaves like serpentine, yields water and has a decidedly serpentinous appearance. Whether this is a step towards the formation of mica, or an entirely independent alteration representing different conditions, is not evident. The latter alternative, however, seems much more probable, and harmonizes better with the facts observed.

The mica, as seen under the microscope, is quite pale in tint with moderate pleochroism, and shows the very low axial angle of biotite, of which it is doubtless the phlogopite variety. As indicated by examination of hand specimens, the mica scales grow into and through the scapolite quite irregularly, with every variety of orientation.

The pyroxene associated with the scapolite has, also, a decided tendency to pass over into mica, and the change is shown in several sections. But, as a rule, the pyroxene has a less regular form than the scapolite, and it is doubtful if any of the more perfect pseudomorphs are to be referred to the former species. It must be admitted, however, that a positive conclusion upon this point can hardly be based upon such crude forms as the pseudomorphs present. The intimate mingling of scapolite and pyroxene in several sections makes it probable that some of the pseudomorphs are of composite origin, in which case the

form might be derived from either one of the minerals involved.

Among the large variety of pseudomorphs after scapolite, mica holds an important place, and many instances of its occurrence have been described, particularly in Europe. Nevertheless, as so often happens in phenomena of this kind, it is by no means easy to account for the details of the process of alteration. The necessary magnesia is readily afforded by the surrounding limestone; indeed, magnesian pseudomorphs, notably talc and serpentine, are abundant throughout the limestone belts of Northern New York. But the sources of the iron, potash and fluorine, together with the precise nature of the chemical reactions involved, remain a matter of great uncertainty.

In connection with this alteration of scapolite, two specimens of the same mineral in the Root collection of Hamilton College are of interest. On one of these, from Edwards, minute crystals of pale yellowish-green epidote partially coat the surface of, and penetrate cracks in, the stout light-gray crystals of scapolite. While this cannot be classed as a clear case of pseudomorphism, it can hardly be questioned that the epidote has grown at the expense of the scapolite, and would have entirely replaced the latter mineral had the process not been checked by changing conditions.

As is the case with mica, epidote is a not uncommon pseudomorph after scapolite, occurring in a number of European localities.*

The second specimen, above referred to, comes from Pierrepont, and consists of more slender crystals of scapolite associated with dark-green pyroxene. Some of the scapolite crystals are coated with a thin layer of garnet, and this mineral penetrates the scapolite in sinuous threads and bands. As in the previous case, the relation between the two minerals can hardly be accidental and is such as to suggest that the garnet has derived a part of its constituents from the scapolite, and might, ultimately, have entirely replaced the latter mineral. The alteration of garnet to scapolite is described by Cathrein,† but the opposite change, above indicated, the writer has not found treated.

It is unfortunate that the very limited supply of material interferes with a more thorough study of both these latter examples of alteration.

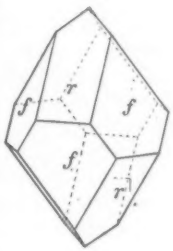
Hamilton College, Clinton, N. Y., May, 1897.

* Roth, Allg. Chem. Geol., i, p. 391.
† Zeitschr. f. Krystall., x, p. 433.

ART. XXXVI.—*On the Chemical Composition of Hamlinite and its Occurrence with Bertrandite at Oxford County, Maine;* by S. L. PENFIELD.

IN the summer of 1890, Mr. W. E. Hidden and the author published a short description of a rhombohedral phosphate occurring with the rare minerals herderite and bertrandite at Stoneham, Maine. Only a single specimen, showing a few minute crystals, was ever found at the locality, and the investigation was therefore incomplete, being confined to determinations of the crystallization and physical properties and the identification of phosphorus, aluminium, fluorine and water, while from its association it was supposed that it would also contain beryllium.

The mineral was named *hamlinite* in honor of Augustus C. Hamlin of Bangor, Maine, who has always taken a keen interest in collecting and studying the minerals of his State and especially the beautiful tourmalines from Mt. Mica and vicinity. As stated in the original article, the incomplete description was published for the purpose of calling attention to a mineral which would probably prove to be interesting, and also in hopes that others would be led to look for the mineral and find it. This hope has not been in vain, for Mr. Lazard Cahn of New York had the good fortune to discover among a suite of minerals from Oxford County, Maine, some specimens showing rhombohedral crystals of a mineral, unknown to him, which he gave to the author, suggesting that they might prove to be the rare mineral hamlinite. It is hoped that additional information may be obtained concerning the exact locality at which the mineral is found, so that a supply of specimens may become available for distribution. The mineral was readily identified as hamlinite by its rhombohedral crystallization, basal cleavage, positive double refraction, and blowpipe reactions.



1.

The crystals are implanted upon feldspar and muscovite and are associated, like the ones from Stoneham, with apatite, herderite and rarely bertrandite. The crystals present two prominent habits: One a combination of the rhombohedrons $r, 10\bar{1}1$ and $f, 02\bar{2}1$, developed as shown in the accompanying figure. On these crystals there are occasionally small basal planes and slight horizontal striations on the rhombohedral faces near their juncture with the base. The other habit is essentially a combination of the hexagonal prism of the first order, $10\bar{1}0$, with the base, but, owing to a vicinal

development and rounding, the prismatic faces have a tendency toward a steep rhombohedron, and the basal planes are marked by triangular prominences.

The crystals attain at times a diameter of 3 to 4$^{mm}$, but are not well adapted for measurement owing to the vicinal character of the faces. The following measurements can claim to be only approximations, since there were usually several reflections of the signal of the goniometer from each face, and it was impossible to tell upon which one the cross-hair of the telescope should be placed. The calculated angles are those derived from measurements of the hamlinite from Stoneham. $c$=1·135, but the crystals from that locality showed a vicinal development of their faces, and the values can not, therefore, be considered as very exact.

| | Measured. | Calculated. |
|---|---|---|
| $r \wedge r$, $10\bar{1}1 \wedge \bar{1}101$ = | 88° 41′ | 87° 2′ |
| $f \wedge f$, $02\bar{2}1 \wedge \bar{2}021$ = | 109 11 | 108 2 |
| $r \wedge f$, $10\bar{1}1 \wedge 02\bar{2}1$ = | 54 44 and 54° 47′ | 54 1 |

It was found to be practically impossible to select by hand-picking a sufficient quantity of the pure hamlinite crystals for an analysis, and, therefore, a number of specimens upon which the crystals were observed were pulverized, and the hamlinite separated from the other minerals by means of the heavy liquids. Apatite, however, could not be thus separated, but, owing to the fact that hamlinite is almost insoluble in boiling dilute hydrochloric acid, it was possible by treatment with successive portions of acid until the solution gave no test for calcium to remove the apatite completely. All possible precautions were taken to make the separation and purification of the mineral as complete as possible, and the mineral, when examined with the microscope, showed no visible impurity. The specific gravity of the hamlinite varied considerably, that portion which was taken for the chemical analysis being between 3·159 and 3·283, while some of the mineral was still a trifle higher and some a little lower.

A qualitative analysis indicated the presence of aluminium, strontium, barium, phosphorus, fluorine and water, and the absence of calcium and beryllium. In the quantitative analyses the strontium and barium were weighed together as sulphates and subsequently separated as recommended by Fresenius,* by a double precipitation of the barium as chromate. The fluorine was weighed as calcium fluoride, and the latter was tested and found to be pure by conversion into sulphate. Water was determined in two ways; first by fusing with dry sodium carbonate and weighing the water directly,† second by loss on

* Zeitsch. für anal. Chemie, xxix, p. 413, 1890.

† This Journal, xlviii, p. 37, 1894.

ignition, using a weighed quantity of lime to retain the fluorine.* The air-dry powder lost only 0·16 per cent by heating to 100°, and the water was not expelled until the mineral was heated nearly to redness, thus indicating the presence of hydroxyl.

The results of the analysis are as follows:

| | | | | | Average. | | Ratio. | | |
|---|---|---|---|---|---|---|---|---|---|
| $P_2O_5$ | | | 28·92 | | 28·92 | | ·204 | | 1·00 |
| $Al_2O_3$ | 32·29 | 32·30 | | | 32·30 | | ·316 | | 1·55 |
| $Fe_2O_3$ | | ·90 | | | ·90 | | | | |
| SrO | 18·33 | 18·53 | | | 18·43 | | ·178 | ·204 | 1·00 |
| BaO | 4·10 | 3·89 | | | 4·00 | | ·026 | | |
| $H_2O$ | | | 11·93 | 12·07 | 12·00 | ÷9= | 1·333 | 1·435 | 7·03 |
| F | 1·93 | | | | 1·93 | | ·102 | | |
| $SiO_2$ | ·96 | | | | ·96 | | | | |
| $K_2O$ | | ·34 | | | ·34 | | | | |
| $Na_2O$ | | ·40 | | | ·40 | | | | |
| | | | | | 100·18 | | | | |
| Oxygen equivalent of fluorine, | | | | | ·81 | | | | |
| | | | | | 99·37 | | | | |

The ratio of $P_2O_5 : Al_2O_3 : (Sr+Ba)O : (OH+F)$ is very nearly 1 : 1·5 : 1 : 7, which gives the formula $Al_3Sr(OH)_7P_2O_7$ or better $[Al(OH)_2]_3[SrOH]P_2O_7$, where strontium is partially replaced by barium and hydroxyl by fluorine.

By the method of preparing the mineral for analysis traces of adhering feldspar and mica could not be wholly avoided, and, although the small quantities of $Fe_2O_3$ and alkalies may belong partly to the hamlinite and partly to impurities, these have been neglected in making the calculations. If the alkalies together with their equivalent of $Al_2O_3$ (1·06 per cent), the $Fe_2O_3$ and the $SiO_2$, in all 3·62 per cent, are deducted from the analysis and the remainder calculated to one hundred per cent, the results are as given below, where they are compared with the theoretical composition, where Sr : Ba = 7 : 1 and OH : F = 13 : 1.

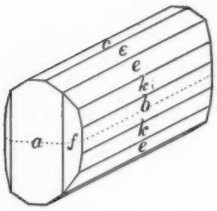
| | Found. | Calculated. |
|---|---|---|
| $P_2O_5$ | 30·20 | 30·31 |
| $Al_2O_3$ | 32·67 | 32·65 |
| SrO | 19·25 | 19·29 |
| BaO | 4·18 | 4·08 |
| $H_2O$ | 12·53 | 12·48 |
| F | 2·01 | 2·04 |
| | 100·84 | 100·85 |
| O=F | ·84 | ·85 |

* This Journal, xxxii, p. 109, 1886.

In its chemical composition hamlinite holds a unique position among minerals, as strontium and barium have never before been observed as essential constituents of a phosphate and this is the first time that a pyrophosphate has been recorded.

*Note concerning Bertrandite Crystals from Oxford County, Maine.*

2.




Associated with the hamlinite just described there was one specimen showing prismatic crystals averaging about $2^{mm}$ in length and $1^{mm}$ in diameter, which proved to be the rare mineral bertrandite. The habit is shown in the accompanying figure and the forms are as follows:

| | | | |
|---|---|---|---|
| *a*, 100 | *c*, 001 | *ϵ*, 011 | *k*, 0·12·1 |
| *b*, 010 | *f*, 130 | *e*, 031 | |

The crystals are in reality twins, two hemimorphic individuals being united by their basal planes, and occasionally the line of twinning may be traced horizontally across the *a*, *f* and *b* faces. The specific gravity was found to be 2·571. The measured angles are given below, together with the calculated values derived from the axial ratio $a:b:c = 0{\cdot}56885:1:0{\cdot}5973$.

| | Measured. | Calculated. | | Measured. | Calculated. |
|---|---|---|---|---|---|
| $f \wedge f$, $130 \wedge 1\bar{3}0$ | = 119° 20′ | 119° 16′ | $c \wedge \epsilon$, $001 \wedge 031$ | = 60° 50′ | 60° 50′ |
| $c \wedge \epsilon$, $001 \wedge 011$ | = 30 50 | 30 51 | $c \wedge k$, $001 \wedge 0{\cdot}12{\cdot}1$ | = 82 20 | 82 4 |

In closing the author desires to express his thanks to Mr. Cahn for calling his attention to this new occurrence of hamlinite and bertrandite.

Laboratory of Mineralogy and Petrography,
Sheffield Scientific School, May, 1897.

# SCIENTIFIC INTELLIGENCE.

## I. Chemistry and Physics.

1. *On the Properties of Highly Purified Substances.*—In consequence of recent experiments showing that many chemical changes take place only in the presence of some substance, presumably water vapor, going to establish the general rule that all chemical changes depend on the presence of this vapor, Shenstone has been led to study the apparent exceptions to this rule more carefully. His first experiments were directed to determine the influence of moisture (1) upon the production of ozone from oxygen by means of the electric discharge, and (2) upon the stability of ozone. The apparatus used was quite elaborate, built up entirely of glass and sealed before the blowpipe. It was filled with oxygen, generated within the apparatus from a mixture of potassium and sodium chlorates mixed with a little solid potash, the ozonizer was set in operation and the resulting ozone carefully dried with phosphoric oxide; this operation being repeated several times. Finally water vapor free from air was admitted to the exhausted tube, and then oxygen, the apparatus being cooled to 0°. The ozonizer was then put into operation and the amount of ozone generated deduced from the resulting contraction. The maximum yield of ozone was 13·6 per cent and the minimum 13·3. Repeating the experiment with the oxygen dried so that the pressure of the aqueous vapor present was assumed to be not over $0{\cdot}0001^{mm}$, the yield never exceeded 11·1 per cent. Moreover, the ozone obtained appeared to be singularly instable. Direct experiment showed that moist oxygen well ozonized, could be maintained at 26·4° for 9 hours with a loss of only 2 per cent, the loss during the last 4 hours being only 0·4 per cent. Dry oxygen, on the other hand, when strongly ozonized and kept at 0° for 33 minutes, lost 1·6 per cent of its ozone. Hence it appears that moderately dry ozone at 0° undergoes decomposition about 30 times as rapidly as the damp gas at 26·4°. On drying the oxygen still more completely (so that the water-vapor pressure had been reduced to $\cdot000{,}000{,}001^{mm}$) only 0·2 per cent of ozone was formed; showing that well-dried oxygen scarcely ozonizes at all. In a second series of experiments, the behavior of carefully dried chlorine, bromine and iodine with well-dried mercury was studied. The chlorine was generated by the electrolysis of fused silver chloride within the apparatus, a large Fleuss pump and two five-fall Sprengels being used to produce the exhaustion. The bromine and iodine used were also purified with great care. The mercury was prepared from mercurous nitrate or mercuric oxide, and repeatedly distilled. All the materials were dried with the greatest care. On introducing the mercury in a glass bulb into a tube and then filling this with the chlorine, bromine or iodine, it was observed that on breaking

the bulb, there was immediate and rapid action in the cold, the chlorine and bromine being absorbed very soon, the iodine more slowly. Hence the author concludes that the action between chlorine, bromine and iodine on the one hand and mercury on the other does not depend on the presence of water vapor. Additional experiments were made to determine the effect of the silent discharge and of direct sunlight upon highly purified chlorine, but with negative results.—*J. Chem. Soc.*, lxxi, 471, May, 1897.

G. F. B.

2. *On the Liquefaction of Fluorine.*—From the properties of the known compounds of fluorine, the conclusion readily follows that fluorine itself can be liquefied only with great difficulty. Advantage was taken therefore of the lecture upon fluorine given by MOISSAN at the Royal Institution in May, to combine the apparatus for its manufacture which he had brought from Paris, with the unequalled facilities possessed by DEWAR at the Institution, for producing low temperatures, in order to attempt its liquefaction, the results of which are given in a joint paper. The fluorine was prepared by the electrolysis of potassium fluoride dissolved in anhydrous hydrofluoric acid. The fluorine gas was freed from the vapors of hydrofluoric acid by means of a bath of alcohol and solid carbon dioxide. The liquefying apparatus consisted of a small cylinder of thin glass having a platinum tube fused into its upper portion, within which was a second tube also of platinum. The gas entered through the annular space between the tubes, passed into the glass envelope and escaped through the inner tube. Liquid oxygen was used as the refrigerant, several liters of it being required. The apparatus being cooled down to the temperature of quietly boiling liquid oxygen (−183°), the current of fluorine gas passed through it without liquefaction and without attacking the glass at this low temperature. On making a vacuum above the oxygen, a rapid ebullition took place and a liquid collected upon the interior of the glass envelope, no gas now escaping from the tube. On closing this tube with the finger, the glass bulb soon became filled with a clear and very mobile yellow liquid, having the same color as the gas in a stratum one meter thick. Hence fluorine liquefies at about −185°. On removing the apparatus from the bath of liquid oxygen, the temperature rose and the liquid fluorine began to boil, evolving abundance of the gas. Experiments were made upon the action of this gas upon substances cooled to very low temperatures. Silicon, boron, carbon, sulphur, phosphorus and reduced iron, cooled in liquid oxygen, did not become incandescent when placed in an atmosphere of fluorine. Nor at this temperature did fluorine displace iodine from iodides. But it still decomposed benzene and turpentine with incandescence at 180°. When a current of fluorine gas is passed through liquid oxygen a white flocculent precipitate is rapidly formed. This thrown on a filter deflagrates violently as the temperature rises.—*C. R.*, cxxiv, 1202, May, 1897; *Chem. News*, lxxv, 277, June, 1897. G. F. B.

3. *On Normal and Iso-pentane from American Petroleum.*—By means of a dephlegmator devised by them, YOUNG and THOMAS were able in 1895 to isolate normal hexane from petroleum ether in a nearly pure state. By using a very short water condenser at the top of this dephlegmator, and by combining with it a regulated temperature still-head, the authors have now succeeded in separating normal pentane from iso-pentane. The material used was a complex mixture of butanes, pentanes, and hexanes with some benzene and a little hexanaphthene. Three fractionings sufficed to eliminate the butanes, hexanes, benzene and hexanaphthene for the most part. Then the residues, of about 1030 grams, were shaken first with concentrated sulphuric acid, then with a mixture of strong nitric and sulphuric acids; being finally treated with caustic potash and dried with phosphoric oxide. The details of the eleventh fractionation are given in a table in which the lowest fractions are mainly iso-pentane and the highest normal pentane; the intermediate ones being mixtures of these. The fall in temperature of the vapor during its passage through the still-head is greatest for the middle fractions and least for the highest and purest fractions. After 13 fractionings the middle fractions had become very small and the two pentanes were separately fractionated, the normal pentane 8 times and the iso-pentane 11 times. In this way 175 grams of pure normal pentane and 101 grams of iso-pentane were obtained. The former boiled constantly at 36·1° under a pressure of 754·5$^{mm}$ (or 36·3° at 760$^{mm}$) and the latter at 27·95° at 760$^{mm}$. The constants of the iso-pentane thus obtained were compared with those of the synthetically prepared substance and showed a close agreement.

The properties of the normal pentane thus obtained are given in a separate paper by YOUNG. The boiling point remained absolutely constant at 36·3° at 760$^{mm}$. The specific gravity, determined in the Perkins form of Sprengel tube, was 0·64536—0·64541 at 0° and 0·63313 at 12·91°. The volumes at different temperatures agree closely with those of Thorpe and Jones. The critical temperature was found to be 197·2° and the critical pressure 25100$^{mm}$; one gram having a volume of 4·303$^{cc}$ at the critical temperature. From his results the author shows that the densities of liquid and saturated vapor become equal at the critical temperature and hence defines the apparent critical temperature therefore as the temperature at which the densities of liquid and saturated vapor become equal. This temperature was found to be the same whether the temperature had been previously raised or lowered and whether the volume was constant or variable.—*J. Chem. Soc.*, lxxi, 440, 446, April, 1897. G. F. B.

4. *On the Heat of Combustion.*—The formula of Dulong which gives the heat of combustion of solid and liquid fuels as a function of their composition is as follows:

$$\varphi = 81c + 345\left(h - \frac{o}{8}\right)$$

in which $c$, $h$ and $o$ represent the percentages of carbon, hydrogen and oxygen respectively. If a general expression $\varphi = Ac + Bh - Co$ be taken, the numerical value of the coefficient, $A = 81$, must be maintained, since it corresponds to pure carbon, and all known data (from 8060 to 8140) prove that the figure 81 must really be taken for each per cent unit of carbon in the fuel (the accuracy of the measurements being within the limits of from 1 to 2 per cent of the total heat of combustion.) For hydrogen, however, the coefficient $B = 345$ cannot be maintained, because it has been obtained from data relating to the burning of gaseous hydrogen, while in ordinary liquid or solid fuel the elasticity of the gas is lost. Its hydrogen must be considered as if liquefied and consequently B must not exceed 300, supposing as usual that the resulting water is in the liquid state. In order to find the true coefficients suitable for practical purposes MENDELÉEFF takes the value of $\varphi = 4190$, which is the correct value for cellulose within one per cent, and is also the average of 79 most complete determinations for fat coals (by Maler, Alexeyeff, Damski, Diakonoff, Miklaschewski, Schwanhöfer and Bunge) and the average for naphtha fuel. From this he finds

$$\varphi = 81c + 300h - 26(o - s)$$

($s$ being sulphur). This formula represents with an accuracy of from 1 to 2 per cent the heat of combustion of pure charcoal, coke, coals, lignites, wood, cellulose and naphtha fuels. It applies of course to the best determinations only; especially to those which have been made in a calorimetric bomb where the error is less than 1 or 2 per cent. This formula of course is only an approximate empirical expression of facts; but it corresponds at the same time to the numerical value of the coefficient B for hydrogen which theoretical considerations would lead us to expect.—*J. Chem. and Phys. Soc. Russe*, xxix, 144; *Nature*, lvi, 186, June, 1897. G. F. B.

5. *The capillary constants of molten metals.*—This is the subject of an inaugural dissertation (Göttingen, 1897) by HENRY SIEDENTOPF. The author has employed Quincke's method of obtaining the capillary constants by means of falling drops (1868). Whereas Quincke, however, depended upon the determination of the weight of the drops, the present author has based his results upon the measurement of the curvature of their surface and their size. The metals experimented upon were cadmium, tin, lead, mercury and bismuth. For each the *surface tension* and *specific cohesion* were determined at a temperature near that of fusion. The results are given in the following table:

| | Temperature of fusion. | Surface tension. | Specific cohesion. |
|---|---|---|---|
| Cadmium | 318° | 84·85 | 21·25 |
| Tin | 226° | 62·43 | 17·87 |
| Lead | 325° | 51·94 | 9·778 |
| Mercury | −39° | 46·29 | 6·767 |
| Bismuth | 264° | 43·78 | 8·755 |

6. *Relations between the Geometric constants of a Crystal and the Molecular Weight of its Substance;* by Professor G. LINCK. (Abstract of a paper published in vol. xxvi of Groth's Zeitschrift für Krystallographie.)—The author has already called attention* to the fact that the characteristics of crystals, i. e. their geometric and optical constants, stand in direct relation to the atomic or molecular weight of the elements contained in them. This is most clearly shown in the eutropic series: a eutropic series being defined as a series of substances, crystallizing similarly, but differing, only in that they each contain a different element, though the elements are yet similar according to the periodic system of Mendelćeff. If such a series is arranged according to increasing molecular or atomic weight, then the series, for all characteristics of the crystal, remains unchanged. The fundamental law of these phenomena the author has designated "Eutropy."

For the present investigation it was necessary to know the system to which the crystal belonged, its axial relations, the specific gravity and the atomic weight. Of these, the atomic weights were taken exclusively from Krafft's Lehrbuch der Chemie. The specific gravities were taken from one or the other of the three books of Dana (1893), Rammelsberg (1881), or Websky (1868). So far as it was possible to decide, only such values were used as belonged to chemically homogenous material. In like manner the geometric constants, the axial ratios, were for the most part, and wherever possible, taken from a single author (Groth, Tab. Uebersicht, 1889).

The method employed is stated by the author as follows: If we assume with Fock, that the smallest conceivable crystal is identical with the molecule,—although this is not an essential condition for the further development of the subject here discussed—then the relative size of the molecule may be computed from the volume. This is not the molecular volume, as defined in terms of molecular weight, M, and specific gravity, $d$, according to the formula $\frac{M}{d}$, but the volume of the smallest crystal expressed as a product in terms of its geometric constants. As representing the smallest crystal, instead of the hypothetical actual polyhedron, the author assumes (after Schrauf) an ellipsoid whose volume is proportional to that of the fundamental form. This ellipsoid, designated as the crystal-volume, CV, is therefore regarded as the extreme case of a combination.

The crystal-volume is computed from the crystallographic axes of the fundamental form. These divide the fundamental form into eight irregular tetrahedra of equal volume. Of each one of these we know the length of the three edges corresponding to the axes, and also the three angles $\alpha$, $\beta$, $\gamma$, which these axes form

* Zeitschrift für physikalische Chemie, xix, 193.

with each other. From the above data we have the volume of the tetrahedron $v$, from the formula

$$V = \tfrac{1}{3} abc \sqrt{\sin s . \sin [s-\alpha] . \sin [s-\beta] . \sin [s-\gamma]} .$$

where $s$ represents the half sum of the angles $\alpha$, $\beta$, $\gamma$. The volume of the entire, fundamental form would consequently be eight times as large, or in rectangular coördinates, $V = \frac{4}{3} abc$. The contents of the corresponding ellipsoid is, in rectangular coördinates, where the coördinate axes become the axes of the ellipsoid, $= \frac{4}{3} \pi abc$.

For the volumes of the various crystal systems we have, if we denote the quantity under the radical by A, the following formulas:

I. Regular; $CV = \frac{4}{3} \pi$ (where $a = b = c = 1$).

II. Tetragonal and Hexagonal; $CV = \frac{4}{3} \pi c$ (for $a = 1$), $= \frac{4}{3} \pi a^2$ (for $c = 1$).

III. Rhombic; $CV = \frac{4}{3} \pi ac$ (for $b = 1$), $= \frac{4}{3} \pi bc$ ($a = 1$), $= \frac{4}{3} \pi ab$ ($c = 1$).

IV. Monoclinic and Triclinic;

$$CV = \pi \tfrac{8}{3} ac \sqrt{A} \quad (b = 1), \text{ etc.}$$

For the regular system the ellipsoid is a sphere, for the tetragonal and hexagonal systems an ellipsoid of revolution, and for the others an ellipsoid whose semiaxes are $x$, $y$, $z$.

If the crystal-volume so computed were equal to the actual volume of the smallest crystal, or to that of the molecule, then it would only be necessary to multiply this value by the specific gravity of the substance under consideration in order to obtain its molecular weight in terms of water as the unit. The value of the crystal-volume as computed is, however, only proportional to the actual volume of the molecule, and hence the product, $d . CV$, represents only a value proportional to the molecular or atomic weight, taken with reference to water or hydrogen as the case may be, and this value is to be multiplied or divided by some number in order to give the molecular or atomic weight. Since, however, this number is not known, we are not able to use the computed value $d . CV$. We can use it, however, as soon as we consider the entire eutropic series and apply the law of eutropy to the values thus found.

It is therefore evident, that in the case of eutropic crystals, the crystal-volumes must form a series, such that with increasing atomic or molecular weight they either decrease, or what is more probable, increase. In like manner the products $d . CV$, that is, the crystal-weights, must stand in accurate ratio to each other.

We ask further, are then the computed crystal-volumes of all members of a series mutually equivalent? This also must be answered in the negative, for it must not be forgotten that in each substance the lengths of the coördinate axes are taken with reference to a new unit of length, since in each case we put one axis equal to unity. We ought, however, to refer the crystals of the various members to the same unit of length, and only then

would the computed values, $d.\,CV$ or CV, be equivalent to each other. If the products, $d.\,CV$, were originally equivalent, then the quotients $Q = \frac{d.\,CV}{M}$, where M is the simplest molecular or atomic weight, should be the same for all members of the same series. If we have found the quotient $Q_1$ for one substance, then from this we can obtain the actual equivalent weight $d\,.CV_1 = Q_1\,.\,M$, by multiplying it by the atomic or molecular weight, and by dividing this value by the specific gravity of the substance under consideration we obtain the actual equivalent crystal-volume, $CV_1 = \frac{Q_1\,.\,M}{d}$.

The quotient, $\frac{d\,.\,CV}{M}$, is obtained by dividing the crystal-volume by the molecular volume, $\frac{M}{d}$. The difference between the equivalent weights, $d\,.\,CV$, of a series must, since the weights themselves are proportional to the molecular weights, stand in the same ratio as the difference between the corresponding atomic or molecular weights. This latter proposition includes, however, an extension of all our previous considerations touching isomorphic bodies, possibly even a part of the morphotropic ones.

It only remains to say a few words concerning the relations of heteromorphic modifications of the same substance. It is evident that the molecular weight of heteromorphic modifications stand in some simple rational ratio to each other, and consequently, in connection with the above considerations, it follows that the products, $d\,.\,CV$, must also stand in the same simple ratio, or, that equivalent crystal-volumes possess equal weights.

In presenting the results of his calculations, the author gives a series of thirteen tables. Of these, seven are devoted to heteromorphic modifications of the same substance, as, for example, graphite and diamond, marcasite and pyrite, calcite and aragonite, etc. In all of these cases the crystal-volume (CV), the product of this by the specific gravity ($d\,.\,CV$) and the molecular volume (MV) are given; finally, the quotient of the crystal-volume divided by the molecular volume $\left(Q = \frac{CV}{MV}\right)$ is deduced. These last values agree closely in the case of the substance in each table, only showing such variations as can be explained by the inaccuracy of the data available. For instance, for graphite, $Q = 3{\cdot}732$; for diamond, $Q = 3{\cdot}695$. Again, for calcite, $Q = 0{\cdot}097295$; for aragonite, $Q = 0{\cdot}09730$.

From these tables, then, it appears that the theory above developed is in accord with the facts; further, that in case of the complete knowledge of one modification of a substance the determination of one of the quantities, CV or $d$, of another modification is sufficient for the computation of the other. For example, as soon as the axial ratio and specific gravity of graphite are known

the specific gravity for the regular diamond may be computed. In the case of tetragonal and hexagonal crystals also, either the axis $c$ or $a$, or the specific gravity, may be computed; in the remaining crystal systems, only the specific gravity on the one hand, or the crystal volume on the other may be computed. From the crystal volume one geometric constant may be computed backwards, only in case the others are already known.

Tables VII to XIII give the data and calculated values for a series of isomorphous or eutropic substances, as arsenic, antimony, bismuth; also, beryllium, magnesium, zinc, cadmium; again, aragonite ($CaCO_3$), strontianite ($SrCO_3$), witherite ($BaCO_3$), cerussite ($PbCO_3$), etc. The discussion of these tables, though highly interesting, would require more space than is available here. It must suffice to quote the conclusions deduced by the author from them, as follows:

(1) The actual volumes of the various chemical compounds, if formed into equivalent crystals, stand in a very simple relation to each other.

(2) The weights of these equivalent volumes stand in the same relations to each other as the molecular weights.

(3) The volumes in a eutropic series increase with increasing molecular or atomic weights.

(4) The weights of equivalent volumes always increase with increasing atomic weights.

(5) Bodies which are isomorphous but not eutropic likewise stand in a very simple relation to each other according to their crystal volume or their actual volume as the case may be.

(6) Many crystals which have heretofore been considered eutropic or isomorphic are not so, since they probably possess a larger or smaller molecular weight according to the number of atoms.

7. *The Induction Coil in practical work, including Röntgen Rays;* by Lewis Wright. 172 pp. London, 1897 (Macmillan & Co.).—This little volume, by a well known writer, appears opportunely at a time when the induction coil is being called upon for active use more generally than ever before. Many of the workers experimenting with X-rays have not had the advantages of extensive practice in the laboratory, and they especially, as well as others, will be grateful to the author for preparing this excellent summary of the subject.

## II. Miscellaneous Scientific Intelligence.

1. *British Association.*—The sixty-seventh annual meeting of the British Association for the Advancement of Science was held at Toronto from August 18 to 25. It was a more than usually notable occasion, rendered so chiefly by the number and character of the scientific men who came from England to attend it, also by the enthusiastic work of the Canadians at home, and further by the coöperation of members of the American Associa-

tion. The opening address was delivered by the President, Sir John Evans, and other valuable addresses and lectures marked the meeting; numerous important papers were read in the different sections. After the close of the meeting various excursions were undertaken, one of them to the Pacific Coast. The Association is to meet at Bristol next year and in Dover in 1899.

2. *Notes on Greenland glaciation.*—Prof. R. S. Tarr has contributed numerous interesting details to our knowledge of the glacial phenomena exhibited on the west coast of Greenland.*

In the paper on the Cornell glacier (Bull. Geol. Soc. Am., vol. viii, pp. 251–268, pls. 25–29, March, 1897) he maintains that the angular topography does not necessarily indicate freedom from ice invasion,—that the upper Nugsuak peninsula has all been glaciated—that the glacier has recently withdrawn and is now in process of retreat, with a slight recent advance preceding this retreat.

Professor T. C. Chamberlin, reviewing this paper in Science (vol. v, pp. 748–753, May, '97) criticizes some interpretations there made, which the author defends in a later communication (l. c., p. 804).

In the American Geologist the author has described the remarkable "Rapidity of weathering and stream erosion in the Arctic latitudes (vol. xix, pp. 131–136). In a later paper, on "Evidence of Glaciation in Labrador and Baffin land" (vol. xix, pp. 191–197, March, 1897), observations on the shores of Labrador and Baffin land lead him to conclude that glaciation has been general over these surfaces, and that the ice has withdrawn from these regions in very recent times.

In another paper, "Valley Glaciers of the upper Nugsuak peninsula, Greenland" (vol. xix, April, 1897, pp. 262–267), description is given of the valley glaciers, and the "dying glaciers," which are interpreted as the last traces of retreating glacial sheets. H. S. W.

3. *Revision of the Apodidæ.*—Charles Schuchert, in a recent article in the Proceedings of the U. S. Nat. Museum (No. 1117, vol. xix, pages 671–676). *On the fossil Phyllopod genera, Dipeltis and Protocaris, of the family Apodidæ*, revises the genus *Dipeltis* Packard, describes a new species from the Lower Coal Measures, Morris, Ill., and shows the relation of Dipeltis to *Apus*, rather than *Cyclus*. In rearranging the family Apodidæ, a new subfamily *Apodinæ* is proposed, to include the Cambrian genus *Protocaris* and the recent genera *Lepidurus* and *Apus*; and another new subfamily *Diplitinæ* is proposed, to include the Marine Upper Carboniferous *Dipeltis* Packard. H. S. W.

4. *New Meteorite from Canada.* (Communicated.)—The Geological Survey of Canada has recently acquired, through the instrumentality of its Director, Dr. G. M. Dawson, a mass of meteoric iron, which it is proposed to designate as the Thurlow meteorite. It was found by Mr. E. S. Leslie, Jr., May 12th, 1888,

* See this Journal, vol. iii, pp. 223–229 and 315–320.

on about the center of the twenty-eighth lot of the sixth concession of the township of Thurlow, Hastings County, in the province of Ontario. This meteoric iron, which would appear to have been brought to the surface by ploughing, is described by Dr. Hoffmann as an irregularly-shaped, truncated pyramidal mass, with a more or less rectangular base, measuring 16 by 13·5, or including an elongated projection, 17 centimeters, in its diameters, and 10 centimeters in height; its weight is 5·42 kilos. The entire surface is pitted, and coated with a chestnut-brown, slightly glimmering, film of oxide of iron.

5. *Observations on Popocatepetl and Ixtaccihuatl;* by OLIVER C. FARRINGTON. Field Columbian Museum. Publication 18, Geol. series, vol. i, No. 2, pp. 71–120, pls. vii–xviii, 1897.—In this brief account of a personal examination of this interesting geological region Dr. Farrington has given a vivid description of the geographic and geologic features of the mountains, perfecting his sketch by reference to particulars recorded by previous observers, and illustrating the paper by numerous reproductions of photographs. H. S. W.

6. *L. Évolution régressive en Biologie et en Sociologie,* par MM. JEAN DEMOOR, JEAN MASSART et EMILE VANDERNELDE, pp. 1–324, figs. 84, Paris, 1897. (Bibliothèque scientific internationale, Felix Alcan.)—The authors, being specialists in the fields of biology and sociology, have combined forces to discuss the analogies between the phenomena of "règression" in the evolution of organism and regression in society. They conclude that the transformations of organs and of institutions are always accompanied by regression, that regressive evolution is irrevertible and, consequently, with a few exceptions, is more or less final (*nettes*), and that regressive evolution is caused by limitation of the means of subsistence—food, capital or the forces of labor, etc. The book is modern and full of suggestive thoughts, both for the biologist and for the student of social problems. H. S. W.

7. *The Birds of Colorado;* by W. W. COOKE. 141 pp. Fort Collins, Colorado (The State Agricultural College, Agricultural Experiment Station, Bulletin No. 37).—This pamphlet gives a list of the birds of Colorado, so far as identified up to the present time, with notes on their distribution, habits of migration, etc. The State is unusually rich in number of birds, more so than any other in the Union except Nebraska. A complete bibliography of Colorado ornithology is given in pp. 20 to 39. Copies of this publication may be obtained free of charge by addressing the Director of the Experiment Station at Fort Collins.

8. *The Mammoth Cave of Kentucky: an illustrated Manual;* by HORACE C. HOVEY and RICHARD ELLSWORTH CALL. 107 pp. 1897. Louisville, Ky. (John P. Morton & Co.)—Future visitors to the Mammoth Cave will be glad to have in hand this full and well-illustrated guide book to that most interesting locality.

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*Lesves*, Prov. Namur, Belgium—Chondrite, date of fall, 13, iv, 1896, fragments with crust, 125 gr., $170.00; 32 gr., $43.00; 2.6 gr., $6.00. Small fragments with crust, p. 1 gr., $2.50.

*Zebrak* (Praskoles), Bohemia—Chondrite, date of fall, 14, x, 1824. Fragment with crust, 51 gr., $107.00.

*Beaconsfield*, Victoria, Australia—Siderite, discovered 1896. Slices of various size, per 1 gr., $0.25. Detailed Price-List on application.

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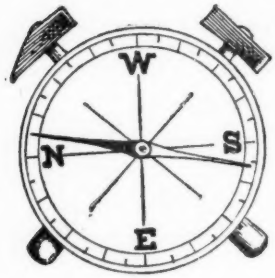


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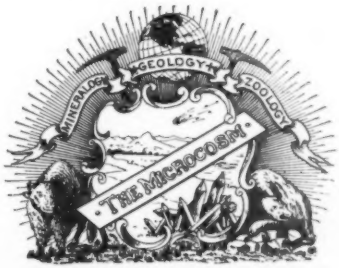


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| Cherokee (1), | 20 to 40 " | New Concord, | 7 to 12 " |
| Kendall Co., | 18 to 20 " | Winnebago, | 8 to 20 " |
| Rockwood (2), | 5 to 8 " | Beaver Creek (6), | 25 " |
| Doña Inez (3), | 10 to 15 " | Kessen, | 15 " |
| Llano del Inca (3), | 8 to 12 " | Pultusk, | 13 to 15 " |

(1) Described in this Journal Sept., 1895. (2) Ibid Nov., 1897. (3) Proc. Roch. Acad. Sci. Vol. 1. (4) This Journal Aug., 1888. (5) Ibid July, 1893. (6) Ibid June, 1894.

**EDWIN E. HOWELL, 612 17th St., N. W., Washington, D. C.**

# IX.

## LIST OF ALL KNOWN MINERALS CLASSIFIED ACCORDING TO DANA.

("*System of Mineralogy*," Sixth Edition, 1892)

### WITH COMPLETE SUPPLEMENT.

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The first synopsis of Dana's *System of Mineralogy* was published in the *Naturalist's Agency Catalogue*, issued by us in 1876. Subsequently, similar lists appeared elsewhere. The original synopsis, or "Table of Species," gave in a condensed form the physical and chemical characters of species, but did not mention varieties or sub-species.

In the present numerical list, the number and name of every distinct species is given in **black type,** and following, the crystallization and the chemical composition in words and symbols. The old dualistic formula is employed, being generally preferred—*e. g.*, in comparing Stephanite, $5Ag_2S.Sb_2S_3$, with Polybasite, $9Ag_2S.Sb_2S_3$, their relationship and composition are better explained than when written $Ag_5SbS_4$ and $Ag_9SbS_6$.

The varieties and sub-species, or "related compounds," are given in *italics*. The list is intended to include all varieties of any importance, although many obscure or merely local names are omitted. The enumeration of pseudomorphs and other alterations constitutes another new and desirable feature. The Hydrocarbon compounds are briefly described.

THE SUPPLEMENT notices all minerals not described in the main text of Dana's *System*. The original publications were carefully reviewed and these references, dating back to the middle of 1891, are cited.

Serving as a check-list and as a useful work of reference, it is confidently hoped that this list will meet with the universal approval accorded by students to the earlier edition. The thanks of the compiler are due to Prof. E. S. Dana for valuable suggestions, kindly made during the preparation of the manuscript.

INDEX.—The position of any mineral in the following list may be found by referring to the Alphabetical Price List and Index in the preceding pages.

**267. Pyroaurite.** Hexagonal; a hydrous magnesium and iron oxide, $Fe_2O_3.6MgO.15H_2O$(?).

**268. Chalcophanite.** Rhombohedral; a hydrated manganese and zinc protoxide and manganese dioxide, $(MnZn)O.2MnO_2.2H_2O$.

**269. Psilomelane.** Massive; a hydrous manganese manganate, $H_4MnO_5$(?).

RELATED :—

1. *Wad* :—
   (a) *Bog manganese,*
   (b) *Asbolite,*
   (c) *Lampodite.*
2. *Lithiophite,*
3. *Varvicite.*

APPENDIX TO OXIDES.

*Bernonite,*
*Delafossite,*
*Hetaerolite,*
*Hetrogenite,*
*Heubachite,*
*Hydrated titanic oxide,*
*Hydrofranklinite,*
*Hydroplumbite,*
*Namaqualite,*
*Pelagite,*
*Rabdionite,*
*Transvaalite,*
*Winklerite.*

# VI. OXYGEN-SALTS.

## 1. Carbonates.

### A. ANHYDROUS CARBONATES.

1. CALCITE GROUP. $RCO_3$. Rhombohedral.

**270. Calcite.** Rhombohedral; calcium carbonate, $CaCO_3$.

A. VARIETIES BASED ON CRYSTALLIZATION AND IMPURITIES.

I. *Ordinary* :—
   (a) *Dog-tooth Spar,*
   (b) *Nail-head Spar,*
   (c) *Iceland Spar,*
   (d) *Brunnerite,*
   (e) *Reichite,*
   (f) *Fontainebleau limestone,*
   (g) *Hislopite.*

II. *Fibrous and lamellar*:—
   (a) *Satin Spar,*
   (b) *Argentine,*
   (c) *Aphrite.*

III. *Granular massive to cryptocrystalline.*

1. *Granular limestone* :—
   (a) *Statuary marble,*
   (b) *Cipolin,*
   (c) *Giallo antico,*
   (d) *Siena,*
   (e) *Mandelato,*
   (f) *Bardiglio,*
   (g) *Turquoise-blue,*
   (h) *Verd-Antique.*

2. *Hard compact limestone (marbles)* :—
   (a) *Black,*
   (b) *Yellow,*
   (c) *Red,*
   (d) *Fetid,*
   (e) *Panno-di-Morte,*
   (f) *Marble of Languedoc,*
   (g) *Griotte,*
   (h) *Sarencolin,*
   (i) *Bird's-eye,*
   (k) *Shell-marble,*
   (l) *Madreporic marble,*
   (m) *Encrinal,*
   (n) *Lumachelle,*
   (o) *Ruin-marble,*
   (p) *Lithographic stone,*
   (q) *Breccia marble,*
   (r) *Pudding stone,*
   (s) *Hydraulic limestone.*

3. *Soft compact limestone* :—
   (a) *Chalk,*
   (b) *Calcareous marl.*

4. *Concretionary massive*:—
   (a) *Oolite,*
   (b) *Pisolite.*

5. *Deposited by calcareous waters* :—
   (a) *Stalactites,*
   (b) *Stalagmite,*
   (c) *Mexican onyx,*
   (d) *Travertine,*
   (e) *Calc Tufa,*
   (f) *Agaric mineral,*
   (g) *Rock-meal.*

B. VARIETIES BASED UPON COMPOSITION :—

1. *Dolomitic calcite,*
2. *Baricalcite,*
3. *Strontianocalcite,*
4. *Ferrocalcite,*
5. *Manganocalcite,*
6. *Zincocalcite,*
7. *Plumbocalcite.*

ALTERS TO :—Dolomite, Calamine, Siderite, Malachite, Azurite, Gypsum, Smithsonite, Barite, Fluorite, Limonite, Göthite, Hematite, Minium, Meerschaum, Chlorite, Quartz, Chalcedony, Garnet, Feldspar, Mica, Pyrolusite, Hausmannite, Manganite, Marcasite, Galena, Sphalerite, Native copper.

RELATED :—*Thinolite, Predazzite Pencatite.*

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